LITTLE MASTERPIECES OF SCIENCE


Simon Newcomb.

Little Masterpieces of Science

Edited by George Iles

THE SKIES AND THE EARTH

By

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NEW YORK
DOUBLEDAY, PAGE & COMPANY
1902

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GENERAL INTRODUCTION

THIS is the golden age of science, a time of creative energy, broadening horizons, new revolutionary truth—an age which the race for centuries to come will esteem great and memorable as the epochs of Pericles, Augustus or Elizabeth. Like travel-worn wayfarers, whose delight in a new and commanding prospect suffers subtraction in the fatigues and perplexities of their journey, the strife through which the great conquests of our time have been reached prevents our prizing them as they deserve. In eras of the past triumphs have been won in the fields of empire, art, imagination; those of this age are in the universal realms of science. Not a few men of prophetic vision had glimpses of these triumphs long ago. Nearly two centuries have passed since Alexander Pope could say:—

> All are parts of one stupendous whole,
> Whose body Nature is, and God the soul;
> That, chang'd thro' all, and yet in all the same;
> Great in the earth, as in th' ethereal frame:
> Warms in the sun, refreshes in the breeze,
> Glows in the stars, and blossoms in the trees,
> Lives thro' all life, extends thro' all extent,
> Spreads undivided, operates unspent.

And how much richer is Nature, as we know it to-day, than the Nature of the times of Queen

Anne! Not only has man been winning knowledge of her in a thousand fields of exploration, experiment and philosophy, but each of the myriad strands in her skein is traced as subtly bound to every other in ways unimaginable to the most piercing intellects of eras past. Some of the finest of Pope's verse was inspired in the garden he loved to pace, but how much more he would see around him there were he living now! He would find the whole scheme of heavens and earth implicated in that garden's beauty. Its soil telling of forces of storm and heat and chemic war, all at work, in time too extended for computation, to grind primeval rock to fertility. He would see the incomparable tints of every flower conferred by diverse elements aflame in an orb a celestial diameter away; elements akin to the flower's own substance. Other indebtedness would be detected in the tribes of buzzing insects surrounding each blossom, insects, which, while sipping a flower, lend vital aid in continuing its race. No hue or scent here without its use in enticement of this winged ministry! And were the poet's garden only various enough in its tenantry, he might count among his flowers many strictly conforming to the mould of their insect visitors. Wheresoever he might turn his eye in the whole realm of Nature he would see it fuller, richer; its every province more intimately interlaced than when he penned his eloquent Essay on Man.

Whilst the study of Nature has been revealing

so much as the generations have swept along, there has been a parallel advance in knowledge at work, and a parallel alliance there of near and remote. As the web of science is unfolded the more closely do we find its threads knit together.

At the beginning of the nineteenth century certain salts of silver were found sensitive to light, and photography was born. In its latest employment it has reproduced books; seized every detail of a bird's flight; enabled the rainbow to paint its every hue; depicted stars and nebulæ far beyond telescopic vision; caught the shadow of a bullet buried in human bones. Progress in photography is no more than abreast of progress in chemistry, electricity, engineering. Every discovery of a cardinal fact or law extends the range of applied science with a bound, and with a bound which ever lengthens. For each fact and law has a vital tie with every other, and adds one to the multiplier enriching thought and life; when the capital of science increases, so also does the rate of interest at which it compounds.

In its material and immediate sphere, we are in little danger of forgetting the rapid growth of the wealth of science. We are daily informed of some fresh marvel of ingenuity in railroad appliance, in the creations of naval and engineering architecture. Every newspaper tells us of some new piece of scientific ingenuity—electric, telescopic, chemic—all intended to enlarge human powers, or to confer upon man powers wholly new. Remarkable as all these practical applica-

tions of science may be, it is not in these so much as in its broadening and correction of human thought that this age will be memorable for all time. Upon men not yet old, new heavens and a new earth have dawned in the successive decades of their lives. A generation or so ago the word "universe" had a significance faulty and meagre in comparison with its meaning to-day. To be sure, the visible contents of space were regarded as one, but that there was an equal unity of law, of sequence in nature, was not understood. Then, current theories of the universe were theories of creations, annihilations, suspensions of natural law. Year by year has science advanced until order has at last dislodged magic from every stronghold of her ancient territory; the universe has been discovered to be in agreement with itself.

In an important point of view the history of modern knowledge is the history of identification, of tracing the many in the one, or reducing what seemed antagonism to concord, difference to unity. It was in physics that this process of identification first took place. Fifty years ago electricity was imagined a fluid. Chemical affinity was deemed essentially different from either heat or mechanical motion. Observers and experimenters have in our day established that every phase of physical force is in its last analysis motion, and is therefore identical with every other; that throughout all its maze of transformation, its quantity remains ever the

same. That all phases of energy are comparable to the mutually convertible orbits which the various parts of a machine may describe in air—volutes, spirals, circles, waves. And with respect to matter, as well as motion, there seems to be good ground to think it fundamentally one. The spectroscope displays an increasing simplicity of substance the higher the temperature of a star, so that it would seem that the "elements" of chemistry may be but the variously grouped aggregations of some simplest substance. A strange confirmation of the faith in transmutation entertained by alchemists of old! Half way in the course of the last century physical science was as it were a succession of islands in an archipelago, each isolated and distinct from its neighbours. Even while we watched they arose, and the retiring waters showed a connected continent, speedily parcelled out among sturdy bands of explorers. That the wave circling out from the paddle, the musical note pulsating the air, the throb of electricity, the grasp of magnetism, the impulse of gravitation, the vibrant heat and light shot forth from fuel, sun and star, the stimulus to chemic union, the subtle energy of animal and plant, are in all their diversity fundamentally one, is a conception as great as ever dignified human thought. Truly the faithful, patient men, whose gift to mankind it is, are

> Unifiers of a united world,
> For wheresoever their clear eye-beams fell
> They caught the footsteps of the same.

Of like mould are the students who have still further broadened the glory of our age by proving evolution to be the law of Nature's history; who have shown that, however structureless the universe may have been in the distant past—whether glowing solid, seething liquid, or lambent gas—yet that within its bosom lay all the possibilities of the worlds around us. Lyell laid the foundation of the theory of development when he established the sufficiency of forces at work in modern times to account for the earth's geological history. Spectroscopy continued the impulse in a new path by giving support to Kant's nebular hypothesis, and by showing the innumerable host of heaven to be built up of like materials with our globe. Von Baer added suggestive corroboration by his discovery that the history of the development of a race from lower forms is recapitulated in the transformations undergone by every individual before birth. The arch of evidence of evolution arose rapidly under the hands of these men, yet its span required an expianation of how species came to be, and how man had ascended from humble forms of life. An arch all but finished may lack only a keystone to complete it; that added, it has strength and sureness; that wanting, it has neither. When Darwin supplied the keystone of evolutionary evidence in the facts of natural selection, then, and then only, did the law of universal development fairly come into the possession of mankind. A law, surely, of profoundest significance. By

demonstrating nature to be a family, it gives classification the relationship of descent as its true basis. To education it indicates a new method, and the best, for the order in which the faculties unfold is manifestly the order in which they can most fruitfully be trained.

It makes possible writing nature's history backward to the time when only chaos was, chaos as wonderful in the order enwrapped within it as the universe developed in the æons. The universe it makes one in a new sense, for it binds together in a single web of causation systems, worlds, life, mind. To have lived when this great truth was advanced, debated, established, is a privilege to men rare in the centuries. The inspiration felt by those who have seen the old, isolating mists dissolve until each branch of knowledge can be traced to convergence in one mighty tree, is not to be known to men of a later day, who are of those who inherit, not of those who win. Fortunate are they who live in a golden age like this, when ideas of the first magnitude mount above the horizon, who are young enough to be adequately impressed by them, sufficiently mature to feel their significance and think out their implications.

Whilst our conceptions of Nature have been immeasurably extended, in that her forces have been shown to be essentially one, and her substance essentially one, despite an ever-unfolding variety and complexity; in that law has been proved to reign throughout space in every mani-

festation of force, and throughout time in every transformation of matter, yet more has betided the great epoch in which we live. Nothing else than the dignifying and perfecting the instrument by which these tremendous accessions to thought have been carved out—the scientific method—now confessed the one trustworthy means for the winning of all truth. It is too soon to forecast its future victories, for the men who wield it are too few and too newly drilled to have more than begun an attack which not only in the sphere of natural science, but in the fields of art, history and criticism, in reforms moral and religious, social and political, must ever gather strength and sweep. Yet already the vanguard of the army of science is assembled and in motion; we can see the direction its forces are taking, and the discipline under which they advance. In all its work, artistic, literary, critical, in fields of reform, it means reality, accuracy, fidelity to the directly observed and carefully comprehended fact. It disregards traditions, legends and guesses, however closely associated with great names or ancient institutions. In their stead it is erecting a new authority, which finds its sanctions in knowledge, in observation, experiment, reasoning; in untiring, impartial verification. Glad when it can find, as it often can, that men of old time had a fore-feeling of modern scientific truth, but under all circumstances loyally pledged to declare exactly what it discovers, however much that loyalty may

cause a valued heritage to be disprized. Triumphs to us inconceivable doubtless await the centuries to come, but there will remain as the inalienable glory of to-day that to the old question, What is truth? it first gave not the old answer, whatsoever has been so considered, but whatsoever can be proved.

In that science has in our age demonstrated what hitherto was only suspected, that the universe has an order intelligible to the very core, it has achieved the religious work of displaying Nature as the manifestation of Supreme Intelligence, not external to it, but immanent in it. What though that order be as yet little understood; the diameter of human ignorance unmeasured! Therein is opportunity and incitement for every man with heart and brain to add to knowledge all he may.

In the series of little books here offered to the public many of the recent triumphs of invention, discovery and exploration are narrated by the men who won them for the world; in other cases a summary of progress has been borrowed from the pages of a careful historian or expositor. A reader who has neither a telescope nor a microscope at command may, nevertheless, be glad to learn something of their revelations. He may have no skill in the use of a test tube or the electric furnace and yet keenly enjoy hearing a chemist recite the new conquests of the laboratory. And in whatever walk of science

he accompanies a master spirit, the benefit will not be wholly on the learner's part. Men of science work all the more happily, with all the better effect, when the public has an intelligent sympathy with their aims and achievements. To further and deepen that sympathy is the purpose of these MASTERPIECES OF SCIENCE.

In some cases the pages here reproduced have been abridged and a few slight changes effected in the text. Here and there a technical term of an unusual kind is followed by a definition in brackets, or a translation is affixed to a foreign word. The notes which preface each successive chapter may serve the reader as windows of outlook upon literature which may gainfully supplement the books which here fill his hand.

GEORGE ILES.

PREFACE

NEW heavens and a new earth to-day meet an observer's eye. To our forefathers, skies, land and sea were held to be little changed from the moment when they left the Master's hand. To-day we learn that the sun and his attendant orbs were once a cloud of slightest texture, of slowest motion, of elements one and the same. With some account of what the sun can teach us, this volume begins, citing one of the ablest expositors of the nineteenth century, Professor Proctor.

The sun, for all his importance to our earth, is but one star amid an uncounted host. In an address by Professor Newcomb he tells us of the profound questions written across the midnight skies. As we read his pages we feel a new sense of the grandeur of the universe, a new reverence for the men who have enlarged its horizons and disentangled its web of law and rule.

Of like dignity is the essay by Professor Young, with its well-grounded hope that the astronomer is soon to gather and garner harvests as rich as ever yet came to his granary of fact and interpretation. These new harvests will doubtless be mainly won by the camera, to be created more accurate and sensitive than the instruments of to-day. Fitly, therefore, a sketch of celestial

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striking phenomena which characterize the progress of terrestrial or planetary magnetic storms.

When we remember that what is true of a relatively great solar disturbance, such as the one witnessed by Messrs. Carrington and Hodgson, is true also (however different in degree) of the magnetic influences which the sun is at every instant exerting, we see that a new and most important bond of union exists between the members of the solar family. The sun not only sways them by the vast attraction of his gravity, not only illumines them, not only warms them, but he pours forth on all his subtle yet powerful magnetic influences. A new analogy between the members of the solar system is thus introduced.

And now we pass on to other discoveries, bearing at once and with equal force upon the relations between the various members of the solar system and upon the position which that system occupies in the universe.

Hitherto we have been considering the teachings of the telescope; we have now to consider what we have learned by means of an instrument of yet higher powers. As I shall have to refer very frequently, throughout this volume, to the teachings of the spectroscope, it will be well that I should briefly describe what it is that this instrument really effects. Were I simply to state the results of its use, without describing its real character, many of my readers would be disposed to believe that astronomers are as

credulous as in reality they are exacting and scrupulous, where new facts and observations are in question.

The real end and aim of the telescope, as applied by the astronomer to the examination of the celestial objects, is to gather together the light which streams from each luminous point throughout space. We may regard the space which surrounds us on every side as an ocean without bounds or limits, an ocean across which there are ever sweeping waves of light either emitted directly from the various bodies subsisting throughout space, or else reflected from their surfaces. Other forms of wave also speed across these limitless depths in all directions; but the light-waves are those which at present concern us. Our earth is as a minute island placed within the ocean of space, and to the shores of this tiny isle the light-waves bear their messages from the orbs which lie like other isles amid the fathomless depths around us. With the telescope the astronomer gathers together portions of light-waves which else would have travelled in diverging directions. By thus intensifying their action, he enables the eye to become cognizant of their true nature. Precisely as the narrow channels around our shores cause the tidal wave, which sweeps across the open ocean in almost insensible undulations, to rise and fall through a wide range of variation, so the telescope renders sensible the existence of light-waves which would escape the notice of the unaided eye.

The telescope, then is essentially a *light-gatherer.*

The spectroscope is used for another purpose. It might be called the *light-sifter.* It is applied by the astronomer to analyze the light which comes to him from beyond the ocean of space, and so to enable him to learn the character of the orbs from which that light proceeds.

The principle of the instrument is simple, though the appliances by which its full powers can alone be educed are somewhat complicated.

A ray of sunlight falling on a prism of glass or crystal does not emerge unchanged in character. Different portions of the ray are differently bent, so that when they emerge from the prism they no longer travel side by side as they did before. The violet part of the light is bent most, the red least; the various colours from violet through blue, green and yellow, to red, being gradually bent less and less.

The prism then *sorts*, or *sifts*, the light-waves.

But we want the means of sifting the light-waves more thoroughly. The reader must bear with me while I describe, as exactly as possible in the brief space available to me, the way in which the first rough work of the prism has been modified into the delicate and significant work of the spectroscope. It is well worth while to form clear views on this point, because so many of the wonders of modern science are associated with spectroscopic analysis.

If, through a small round hole in a shutter,

light is admitted into a darkened room, and a prism be placed with its refracting angle downward and horizontal, a vertical spectrum, having its violet end uppermost, will be formed on a screen suitably placed to receive it.

But now let us consider what this spectrum really is. If we take the light-waves corresponding to any particular colour, we know from optical considerations that these waves emerge from the prism in a pencil exactly resembling in shape the pencil of white light which falls on the prism. They therefore form a small circular or oval image on their own proper part of the spectrum. Hence the spectrum is in reality formed of a multitude of overlapping images, varying in colour from violet to red. It thus appears as a rainbow tinted streak, presenting every gradation of colour between the utmost limits of visibility at the violet and red extremities.

If we had a square aperture to admit the light, we should get a similar result. If the aperture were oblong, there would still be overlapping images; but if the length of the oblong were horizontally placed oblong, the overlapping would be less than when the images were square. Suppose we diminish the overlapping as much as possible; in other words, suppose we make the oblong slit as narrow as possible. Then, unless there were in reality an infinite number of images distributed all along the spectrum from top to bottom, the images might be so narrowed as to not overlap; in which case, of course, there would

be horizontal dark spaces or gaps in our spectrum. Or again, if we failed in finding gaps of this sort by simply narrowing the aperture, we might lengthen the spectrum by increasing the refracting angle of the prism, or by using several prisms and so on.

The first great discovery in solar physics, by means of the analysis of the prism (though the discovery had little meaning at the time), consisted in the recognition of the fact that by means of such devices as above, dark gaps or cross-lines *can* be seen in the solar spectrum. In other words, light-waves of the various gradations corresponding to all the tints of the spectrum from violet to red, do *not* travel to us from the great central luminary of our system. Remembering that the effect we call colour is due to the length of the light-waves, the effect of red corresponding to light-waves of the greatest length, while the effect of violet corresponds to the shortest light-wave, we see that in effect the sun sends forth to the worlds which circle around him light-waves of many different lengths, but not of all lengths. Of so complex and interesting a nature is ordinary daylight.

But spectroscopists sought to interpret these dark lines in the solar spectrum, and it was in carrying out this inquiry—which even to themselves seemed almost hopeless, and to many would appear an utter waste of time—that they lighted upon the noblest method of research yet revealed to man

They examined the spectra of the light from incandescent substances (white-hot metals and the like), and found that in these spectra there are no dark lines.

They examined the spectra of the light from the stars, and found that these spectra are crossed by dark lines resembling those in the solar spectrum, but differently arranged.

They tried the spectra of glowing vapours, and they obtained a perplexing result. Instead of a number of dark lines across a rainbow-tinted streak, they found bright lines of various colour. Some gases would give a few such lines, others many, some only one or two.

Then they tried the spectrum of the electric spark, and they found here also a series of bright lines, but not always the same series. The spectrum varied according to the substances between which the spark was taken and the medium through which it passed.

Lastly, they found that the light from an incandescent solid or liquid, when shining through various vapours, no longer gives a spectrum without dark lines, but that the dark lines which then appear vary in position, according to the nature of the vapour through which the light has passed.

Here were a number of strange facts, seemingly too discordant and too perplexing to admit of being interpreted. Yet one discovery only was wanting to bring them all into unison.

In 1859 Kirchhoff, while engaged in observing the solar spectrum, lighted on the discovery that

a certain double dark line which had already been found to correspond exactly in position with the double bright line forming the spectrum of the glowing vapour of sodium, was intensified when the light of the sun was allowed to pass through that vapour. This at once suggested the idea that the presence of this dark line (or, rather, pair of dark lines) in the spectrum of the sun is due to the existence of the vapour of sodium in the solar atmosphere, and that this vapour has the power of absorbing the same order of light-waves as it emits. It would of course follow from this that the other dark lines in the solar spectrum are due to the presence of other absorbent vapours in its atmosphere, and that the identity of these would admit of being established in the same way, supposing this general law to hold that a vapour emits the same light-waves that it is capable of absorbing.

Kirchhoff was soon able to confirm his views by a variety of experiments. The general principles to which his researches led—in other words, the principles which form the basis of spectrum analysis—are as follows:

1. An incandescent solid or liquid gives a continuous spectrum.

2. A glowing vapour gives a spectrum of bright lines, each vapour having its own set of lines, so that from the appearance of a bright-line spectrum one can tell the nature of the vapour or vapours whose light forms the spectrum.

3. An incandescent solid or liquid shining

through absorbent vapours gives a rainbow-tinted spectrum crossed by dark lines, these dark lines having the same position as the bright lines belonging to the spectra of the vapours; so that, from the arrangement of the dark lines in such a spectrum, one can tell the nature of the vapour or vapours which surround the source of light.

The application of the new method of research to the study of the solar spectrum quickly led to a number of most interesting discoveries. It was found that besides sodium the sun's atmosphere contains the vapours of iron, calcium, magnesium, chromium and other metals. The dark lines corresponding to these elements appear unmistakably in the solar spectrum. There are other metals—such as copper and zinc—which seem to exist in the sun, though some of the corresponding dark lines have not yet been recognized. As yet it has not been proved that gold, silver, mercury, tin, lead, arsenic, antimony, or aluminum exist in the sun—though we can by no means conclude, nor indeed is it at all probable, that they are absent from his substance.* The dark lines belonging to hydrogen are very well marked indeed in the solar spectrum, and, as we shall see presently, the study of these lines has afforded most interesting information respecting the physical constitution of the sun.

* Helium was detected as an element in the solar spectrum in 1868; in 1895 it was discovered as a terrestrial element in the gas liberated from cleveite and some other rare minerals.—Ed.

Now, we notice at once how importantly these researches into the sun's structure bear upon the subject of this treatise. It would be indeed interesting to consider the actual condition of the central orb of the planetary scheme, to picture in imagination the metallic oceans which exist upon his surface, the continual evaporation from these oceans, the formation of metallic clouds, and the downpour of metallic showers upon the surface of the sun. But apart from such considerations, and viewing Kirchhoff's discoveries simply in their relation to the subject of other worlds, we have enough to occupy our attention.

If it could be shown that, in all probability, the substance of the sun consists of materials wholly different from those which exist in this earth, the conclusion obviously to be drawn from such a discovery would be that the other planets also are differently constituted. We could not find any just reason for believing that in Jupiter or Mars there exist the elements with which we are acquainted, when we found that even the central orb of the planetary system exhibits no such feature of resemblance to the earth. But now that we know quite certainly that the familiar elements iron, sodium and calcium exist in the sun's substance, while we are led to believe, with almost perfect assurance, that all the elements we are acquainted with also exist there, we see at once that in all probability the other planets are constituted in the same way. There

may, of course, be special differences. In one planet the proportionate distribution of the elements may differ, and even differ very markedly from that which prevails in some other planet. But the general conclusion remains, that the planets are formed of the elements which have so long been known as terrestrial; for we cannot recognize any reason for believing that our earth alone, of all the orbs which circle around the sun, resembles that great central orb in general constitution.

Now, we have in this general law a means of passing beyond the bounds of the solar system, and forming no indistinct conceptions as to the existence and character of worlds circling around other suns. For it will be seen in the chapter on stars that these orbs, like our sun, contain in their substance many of the so-called terrestrial elements, while it may not unsafely be asserted that all or nearly all these elements, and few or no elements unknown to us, exist in the substance of every single star that shines upon us from the celestial concave. Hence we conclude that around these suns also there circle orbs constituted like ourselves, and therefore containing the elements with which we are familiar. And the mind is immediately led to speculate on the uses which those elements are intended to subserve. If iron, for example, is present in some noble orb circling around Sirius, we speculate not unreasonably respecting the existence on that orb—either now, or in the past, or at some future

time—of beings capable of applying that metal to the useful purposes which man makes it subserve. The imagination suggests immediately the existence of arts and sciences, trades and manufactures, on that distant world. We know how intimately the use of iron has been associated with the progress of human civilization, and though we must ever remain in ignorance of the actual condition of intelligent beings in other worlds, we are yet led, by the mere presence of an element which is so closely related to the wants of man, to believe, with a new confidence, that for such beings those worlds must in truth have been fashioned.

. . . .

We know that the sun is the sole source whence light and heat are plentifully supplied to the worlds which circle around him. The question immediately suggests itself—Whence does the sun derive those amazing stores of force from whence he is continually supplying his dependent worlds? We know that, were the sun a mass of burning matter, he would be consumed in a few thousand years. We know that, were he simply a heated body, radiating light and heat continually into space, he would in like manner have exhausted all his energies in a few thousand years—a mere day in the history of his system. Whence, then, comes the enormous supply of force which he has afforded for millions on millions of years, and which he will undoubtedly continue to afford for at least as long a time as

the worlds which circle around him have need of it—in other words for countless ages yet to come?

Now there are two ways in which the solar energies might be maintained. The mere contraction of the solar substance, Helmholtz tells us, would suffice to supply such enormous quantities of heat, that if the heat actually given out by the sun were due to this cause alone, there would not, in many thousands of years, be any perceptible diminution of the sun's diameter. Secondly, the continual downfall of meteors upon the sun would cause an emission of heat. But though the sun's increase of mass from this cause would not be rendered perceptible in thousands of years, either by any change in his apparent size or by changes in the motions of his family of worlds, yet the supply of heat obtainable in this way can be but small compared with the sun's emission of heat. This follows from the limits between which Leverrier has shown that the total mass of the meteors of our system must certainly lie.

It seems far from unlikely that both these processes are in operation at the same time. Certainly the latter is, for we know, from the motions of the meteoric bodies which reach the earth, that myriads of these bodies must continually fall upon the sun. If the corona and zodiacal light are really due to the existence of flights of meteoric systems circling around the sun, or to the existence in his neighborhood of

the perihelia of many meteoric systems, then there must be a supply of light and heat from this source, though not nearly sufficient to account for the solar emission.

It is worthy of notice, however, that the association between meteors and comets has some bearing on this question. We know that the most remarkable characteristics of comets is the enormous diffusion of their substance. Now, in this diffusion there resides an enormous fund of force. The contraction of a large comet to dimensions corresponding to a very moderate mean density would be accompanied by the emission of much heat. The question is worth inquiring into, whether we can indeed assume that all meteors which reach our atmosphere are solid bodies. Some may be of cometic diffusion. But, be this as it may, it is certain that a large portion of the substance of every comet is in a singularly diffused state. Since the meteoric systems circling in countless millions round the sun are, in all probability, associated in the most intimate manner with comets, we may recognize in this diffusion, as well as in the mere downfall of meteors, the source of an enormous supply of light and heat.

Lastly, turning from our sun to the other suns which shine in uncounted myriads throughout space, we see the same processes at work upon them all. Each star-sun has its coronal and its zodiacal disks, formed by meteoric and cometic systems; for otherwise each would quickly cease

to be a sun. Each star-sun emits, no doubt, the same magnetic influences which give to the zodiacal light and to the solar corona their peculiar characteristics. Thus the worlds which circle round those orbs may resemble our own in all those relations which we refer to terrestrial magnetism, as well as in the circumstance that on them also there must be, as on our own earth, a continual downfall of minute meteors. In those worlds, perchance, the magnetic compass directs the traveller over desert wastes or trackless oceans; in their skies the aurora displays its brilliant streamers; while, amid the constellations which deck their heavens, meteors sweep suddenly into view, and comets extend their vast length athwart the celestial vault.

PROBLEMS OF ASTRONOMY

PROFESSOR SIMON NEWCOMB

[Professor Newcomb, an astronomer of the highest distinction, is Professor of Mathematics and Astronomy at Johns Hopkins University, Baltimore. He has published more than a hundred scientific papers. His numerous works include "The Elements of Astronomy," issued by the American Book Company, New York, 1900; and "The Stars," published by G. P. Putnam's Sons, New York, 1901. The address which follows was given at the dedication of the Flower Observatory, University of Pennsylvania, May 12, 1897, and appeared in *Science*, May 21, 1897. In his work on "The Stars" Professor Newcomb has developed and illustrated the views outlined in this address.—ED.]

THE so-called problems of astronomy are not separate and independent, but are rather the parts of one great problem, that of increasing our knowledge of the universe in its widest extent. Nor is it easy to contemplate the edifice of astronomical science as it now stands, without thinking of the past as well as of the present and future. The fact is that our knowledge of the universe has been in the nature of a slow and gradual evolution, commencing at a very early period in human history, and destined to go forward without stop, as we hope, so long as civilization shall endure. The astronomer of every age has built on the foundations laid by his predecessors, and his work has always formed,

and must ever form, the base on which his successors shall build. The astronomer of to-day may look back upon Hipparchus and Ptolemy as the earliest ancestors of whom he has positive knowledge. He can trace his scientific descent from generation to generation, through the periods of Arabian and mediæval science, through Copernicus, Kepler, Newton, La Place and Herschel, down to the present time. The evolution of astronomical knowledge, generally slow and gradual, offering little to excite the attention of the public, has yet been marked by two cataclysms. One of these is seen in the grand conception of Copernicus that this earth on which we dwell is not a globe fixed in the centre of the universe, but simply one of a number of bodies, turning on their own axes and at the same time moving around the sun as a centre. It has always seemed to me that the real significance of the heliocentric system lies in the greatness of this conception rather than in the fact of the discovery itself. There is no figure in astronomical history which may more appropriately claim the admiration of mankind through all time than that of Copernicus. Scarcely any great work was ever so exclusively the work of one man as was the heliocentric system the work of the retiring sage of Frauenberg. No more striking contrast between' the views of scientific research entertained in his time than in ours can be seen than that seen in the fact that, instead of claiming credit for his great work, he deemed it rather

necessary to apologize for it and, so far as possible, to attribute his ideas to the ancients.

A century and a half after Copernicus followed the second great step, that taken by Newton. This was nothing less than showing that the seemingly complicated and inexplicable motions of the heavenly bodies were only special cases of the same kind of motion, governed by the same forces, that we see around us whenever a stone is thrown by the hand or an apple falls to the ground. The actual motions of the heavens and the laws which govern them being known, man had the key with which he might commence to unlock the mysteries of the universe.

When Huyghens, in 1656, published his *Systema Saturnium* where he first set forth the mystery of the rings of Saturn, which, for nearly half a century, had perplexed telescopic observers, he prefaced it with a remark that many, even among the learned, might condemn his course in devoting so much time and attention to matters far outside the Earth, when he might better be studying subjects of more concern to humanity. Notwithstanding that the inventor of the pendulum clock was, perhaps, the last astronomer against whom a neglect of things terrestrial could be charged, he thought it necessary to enter into an elaborate defence of his course in studying the heavens. Now, however, the more distant the objects are in space—I might almost add the more distant events are in

time—the more they excite the attention of the astronomer, if only he can hope to acquire positive knowledge about them. Not, however, because he is more interested in things distant than in things near, but because thus he may more completely embrace in the scope of his work the beginning and the end, the boundaries of all things, and thus, indirectly, more fully comprehend all that they include. From his standpoint

> "All are but parts of one stupendous whole,
> Whose body nature is and God the soul."

Others study nature and her plans as we see them developed on the surface of this little planet which we inhabit; the astronomer would fain learn the plan on which the whole universe is constructed. The magnificent conception of Copernicus is, for him, only an introduction to the yet more magnificent conception of infinite space containing a collection of bodies which we call the visible universe. How far does this universe extend? What are the distances and arrangements of the stars? Does the universe constitute a system? If so, can we comprehend the plan on which this system is formed, of its beginning and of its end? Has it bounds outside of which nothing exists but the black and starless depths of infinity itself? Or are the stars we see simply such members of an infinite collection as happen to be the nearest to our system? A few such questions as these we are perhaps beginning to answer; but hundreds, thousands, perhaps even millions of years may elapse without our

reaching a complete solution. Yet the astronomer does not view them as Kantian antinomies [contradictions] in the nature of things insoluble, but as questions to which he may hopefully look for at least a partial answer.

The problem of the distances of the stars is of peculiar interest in connection with the Copernican system. The greatest objection to this system, which must have been more clearly seen by astronomers than by any others, was found in the absence of any apparent parallax of the stars. If the earth performed such an immeasurable circle around the sun as Copernicus maintained, then, as it passed from side to side of its orbit, the stars outside the solar system must appear to have a corresponding motion in the other direction, and thus to swing back and forth as the earth moved in the one and the other direction. The fact that not the slightest swing of that sort could be seen was, from the time of Ptolemy, the basis on which the doctrine of the earth's immobility rested. The difficulty was simply ignored by Copernicus and his immediate successors. The idea that Nature would not squander space by allowing immeasurable stretches of it to go unused seems to have been one from which mediæval thinkers could not entirely break away. The consideration that there could be no need of any such economy, because the supply was infinite, might have been theoretically acknowledged, but was not practically felt. The fact is that magnificent as was

the conception of Copernicus, it was dwarfed by the conception of stretches from star to star so vast that the whole orbit of the earth was only a point in comparison.

An indication of the extent to which the difficulty thus arising was felt is seen in the title of a book published by Horrebow, the Danish astronomer, some two centuries ago. This industrious observer, one of the first who used an instrument resembling our meridian transit of the present day, determined to see if he could find the parallax of the stars by observing the intervals at which a pair of stars in opposite quarters of the heavens crossed his meridian at opposite seasons of the year. When, as he thought, he had won success he published his observations and conclusions under the title of "Copernicus Triumphans." But alas! the keen criticism of his contemporaries showed that what he supposed to be a swing of the stars from season to season arose from a minute variation in the rate of his clock, due to the different temperatures to which it was exposed during the day and the night. The measurement of the distance even of the nearest stars evaded astronomical research, until Bessel and Struve arose in the early part of the present century.

On some aspects of the problem of the extent of the universe light is being thrown even now. Evidence is gradually accumulating which points to the probability that the successive orders and smaller and smaller stars, which our

continually increasing telescopic power brings into view, are not situated at greater and greater distances, but that we actually see the boundary of our universe. This indication lends a peculiar interest to various questions arising out of the motions of the stars. Quite possibly the problem of these motions will be the great one of the future astronomer. Even now it suggests thoughts and questions of the most far-reaching character.

I have seldom felt a more delicious sense of repose than when crossing the ocean during the summer months I sought a place where I could lie alone on the deck, look up at the constellations with *Lyra* near the zenith, and, while listening to the clank of the engine, try to calculate the hundreds of millions of years which would be required by our ship to reach the star *a* Lyræ if she could continue her course in that direction without ever stopping. It is a striking example of how easily we may fail to realize our knowledge when I say that I have thought many a time how deliciously one might pass those hundred millions of years in a journey to the star *a* Lyræ, without its occurring to me that we are actually making that very journey at a speed compared with which the speed of a steamship is slow indeed. Through every year, every hour, every minute, of human history from the first appearance of man on the earth, from the era of the builders of the pyramids, through the times of Cæsar and Hannibal, through the period of

every event that history records, not merely our earth, but the sun and the whole solar system with it, have been speeding their way toward the star of which I speak on a journey of which we know neither the beginning nor the end. During every clock-beat through which humanity has existed it has moved on this journey by an amount which we cannot specify more exactly than to say that it is probably between five and nine miles per second. We are at this moment thousands of miles nearer to *a* Lyræ than we were a few minutes ago when I began this discourse, and through every future moment, for untold thousands of years to come, the earth and all there is on it will be nearer to *a* Lyræ, or nearer to the place where that star now is, by hundreds of miles for every minute of time come and gone. When shall we get there? Probably in less than a million years, perhaps in half a million. We cannot tell exactly; but get there we must if the laws of nature and the laws of motion continue as they are. To attain to the stars was the seemingly vain wish of the philosopher, but the whole human race is, in a certain sense, realizing this wish as rapidly as a speed of six or eight miles a second can bring it about.

I have called attention to this motion because it may, in the not distant future, afford the means of approximating to a solution of the problem already mentioned, that of the extent of the universe. Notwithstanding the success of astronomers during the present century in meas-

uring the parallax of a number of stars, the most recent investigations show that there are very few, perhaps hardly more than a score of stars of which the parallax, and therefore the distance, has been determined with any approach to certainty. Many parallaxes, determined by observers about the middle of the century, have had to disappear before the powerful tests applied by measures with the heliometer; others have been greatly reduced, and the distances of the stars increased in proportion. So far as measurement goes, we can only say of the distances of all the stars, except the few whose parallaxes have been determined, that they are immeasurable. The radius of the earth's orbit, a line more than ninety millions of miles in length, not only vanishes from sight before we reach the distance of the great mass of stars, but becomes such a mere point that, when magnified by the powerful instruments of modern times, the most delicate appliances fail to make it measurable. Here the solar motion comes to our help. This motion, by which, as I have said, we are carried unceasingly through space, is made evident by a motion of most of the stars in the opposite direction, just as, passing through a country on a railway, we see the houses on the right and on the left of us being left behind. It is clear enough that the apparent motion will be more rapid the nearer the object. We may, therefore, form some idea of the distance of the stars when we know the amount of the motion.

It is found that, in the great mass of stars of the sixth magnitude, the smallest visible to the naked eye, the motion is about three seconds per century. As a measure thus stated does not convey an accurate conception of magnitude to one not practised in the subject, I would say that, in the heavens, to the ordinary eye, a pair of stars will appear single unless they are separated by a distance of 150 or 200 seconds. Let us then imagine ourselves looking at a star of the sixth magnitude, which is at rest while we are carried past it with the motion of six or eight miles per second which I have described Mark its position in the heavens as we see it today; then let its position again be marked 5,000 years hence. A good eye will just be able to perceive that there are two stars marked instead of one. The two would be so close together that no distinct space between them could be perceived by unaided vision. It is due to the magnifying power of the telescope, enlarging such small apparent distances, that the motion has been determined to so small a period as the 150 years during which accurate observations of the stars have been made.

The motion just described has been fairly well determined for what astronomically speaking are the brighter stars, that is to say those visible to the naked eye. But how is it with the millions of faint telescopic stars, especially those which form the cloud masses of the Milky Way? The distance of these stars is undoubtedly greater,

and the apparent motion is, therefore, smaller. Accurate observations upon such stars have been commenced only recently, so that we have not yet had time to determine the amount of the motion. But the indication seems to be that it will prove quite a measurable quantity, and that before the twentieth century has elapsed it will be determined for very much smaller stars than those which have heretofore been studied. A photographic chart of the whole heavens is now being constructed by an association of observatories in some of the leading countries of the world. I cannot say all the leading countries, because then we should have to exclude our own, which, unhappily, has taken no part in this work. At the end of the twentieth century we may expect that the work will be repeated. Then, by comparing the charts, we shall see the effect of the solar motion and, perhaps, get new light upon the problem in question.

Closely connected with the problem of the extent of the universe, is another which appears, for us, to be insoluble because it brings us face to face with infinity itself. We are familiar enough with eternity, or, let us say, the millions or hundreds of millions of years which the geologists tell us must have passed while the crust of the earth was assuming its present form, our mountains being built, our rocks consolidated and successive orders of animals coming and going. Hundreds of millions of years is, indeed, a long time, and yet, when we contemplate the changes

supposed to have taken place during that time, we do not look out on eternity itself, which is veiled from our sight, as it were, by the unending succession of changes that mark the progress of time. But in the motions of the stars we are brought face to face with eternity and infinity, covered by no veil whatever. It would be bold to speak dogmatically on a subject where the springs of being are so far hidden from mortal eyes as in the depths of the universe. But, without declaring its positive certainty, it must be said that the conclusion seems unavoidable that a number of stars are moving with a speed such that the attraction of all the bodies of the universe could never stop them. One such case is that of Arcturus, the bright reddish star familiar to mankind since the days of Job, and visible near the zenith on the clear evenings of May and June. Yet another case is that of a star known in astronomical nomenclature as 1830 Groombridge, which exceeds all others in its angular proper motion as seen from the earth. We should naturally suppose that it seems to move so fast because it is near us. But the best measurements of its parallax seem to show that it can scarcely be less than 2,000,000 times the distance of the earth from the sun, while it may be much greater. Accepting this result, its velocity cannot be much less than 200 miles per second, and may be much more. With this speed it would make the circuit of our globe in two minutes, and had it gone round and round in our latitudes we should

have seen it fly past us a number of times since I commenced this discourse. It would make the journey from the earth to the sun in five days. If it is now near the centre of our system it would probably reach its confines in a million of years. So far as our knowledge of nature goes, there is no force in nature which would ever have set it in motion and no force which can ever stop it. What, then, was the history of this star, and if there are planets circulating around, what the experience of beings who may have lived on those planets during the ages which geologists and naturalists assure us our earth has existed? Did they see, at night, only a black and starless heaven? Was there a time when, in that heaven, a small faint patch of light began gradually to appear? Did that patch of light grow larger and larger as million after million of years elapsed? Did it at last fill the heavens and break up into constellations as we now see them? As millions more of years elapse will the constellations gather together in the opposite quarter, and gradually diminish to a patch of light as the star pursues its irresistible course of 200 miles per second through the wilderness of space, leaving our universe farther and farther behind it, until it is lost in the distance? If the conceptions of modern science are to be considered as good for all time, a point on which I confess to a large measure of scepticism, then these questions must be answered in the affirmative.

Intimately associated with these problems is

that of the duration of the universe in time. The modern discovery of the conservation of energy has raised the question of the period during which our sun has existed and may continue in the future to give us light and heat. Modern science tells us that the quantity of light and heat which can be stored in it is necessarily limited, and that, when radiated as the sun radiates, the supply must in time be exhausted. A very simple calculation shows that were there no source of supply the sun would be cooled off in three or four thousand years. Whence, then, comes the supply? During the past thirty years the source has been sought for in a hypothetical contraction of the sun itself. True, this contraction is too small to be observed; several thousand years must elapse before it can be measurable with our instruments. Granting that this is and always has been the sole source of supply, a simple calculation shows that the sun could scarcely have been giving its present amount of heat for more than twenty or thirty millions of years. Before that time the earth and the sun must have formed one body, a great nebula, by the condensation of which both are supposed to have been formed. But the geologists tell us that the age of the earth is to be reckoned by hundreds of millions of years. Thus arises a question to which physical science has not been able to give an answer.

The problems of which I have so far spoken are those of what may be called the older astron-

omy. If I apply this title it is because that branch of the science to which the spectroscope has given birth is often called the new astronomy. It is commonly to be expected that a new and vigorous form of scientific research will supersede that which is hoary with antiquity. But I am not willing to admit that such is the case with the old astronomy, if old we may call it. It is more pregnant with future discoveries to-day than it ever has been, and it is more disposed to welcome the spectroscope as a useful handmaid, which may help it on to new fields, than it is to give way to it. How useful it may thus become has been shown by a Dutch astronomer, who finds that the stars having one type of spectrum belong mostly to the Milky Way, and are farther from us than the others.

In the field of the newer astronomy perhaps the most interesting work is that associated with comets. It must be confessed, however, that the spectroscope has rather increased than diminished the mystery which, in some respects, surrounds the constitution of these bodies. The older astronomy has satisfactorily accounted for their appearance, and we might also say for their origin and their end, so far as questions of origin can come into the domain of science. It is now known that comets are not wanderers through the celestial spaces from star to star, but must always have belonged to our system. But their orbits are so very elongated that thousands, or even hundreds of thousands of years

are required for a revolution. Sometimes, however, a comet passing near to Jupiter is so fascinated by that planet that, in its vain attempt to follow it, it loses so much of its primitive velocity as to circulate around the sun in a period of a few years, and thus to become, apparently, a new member of our system. If the orbit of such a comet, or, in fact, of any comet, chances to intersect that of the earth, the latter in passing the point of intersection encounters minute particles which cause a meteoric shower. The great showers of November, which occur three times in a century and were well known in the years 1866–67, may be expected to reappear about 1900, after the passage of a comet which, since 1866, has been visiting the confines of our system, and is expected to return about two years hence.

But all this does not tell us much about the nature and make-up of a comet. Does it consist of nothing but isolated particles, or is there a solid nucleus, the attraction of which tends to keep the mass together? No one yet knows. The spectroscope, if we interpret its indications in the usual way, tells us that a comet is simply a mass of hydro-carbon vapour, shining by its own light. But there must be something wrong in this interpretation. That the light is reflected sunlight seems to follow necessarily from the increased brilliancy of the comet as it approaches the sun and its disappearance as it passes away.

Great attention has recently been bestowed upon the physical constitution of the planets

and the changes which the surfaces of these bodies may undergo. In this department of research we must feel gratified by the energy of our countrymen who have entered upon it. Should I seek to even mention all the results thus made known, I might be stepping on dangerous ground, as many questions are still unsettled. While every astronomer has entertained the highest admiration for the energy and enthusiasm shown by Mr. Percival Lowell in founding an observatory in regions where the planets can be studied under the most favourable conditions, they cannot lose sight of the fact that the ablest and most experienced observers are liable to error when they attempt to delineate the features of a body fifty or one hundred million miles away through such a disturbing medium as onr atmosphere. Even on such a subject as the canals of Mars doubts may still well be felt. That certain markings to which Schiaparelli gave the name of canals exist, few will question. But it may be questioned whether these markings are the fine sharp uniform lines found on Schiaparelli's map and delineated in Mr. Lowell's beautiful book. It is certainly curious that Barnard at Mount Hamilton, with the most powerful instrument and under the most favourable circumstances, does not see these markings as canals.

I can only mention among the problems of the spectroscope the elegant and remarkable solution of the mystery surrounding the rings of

Saturn, which has been effected by Keeler at Allegheny. That these rings could not be solid has long been a conclusion of the laws of mechanics, but Keeler was the first to show that they must consist of separate particles, because the inner portions revolve more rapidly than the outer. The question of the atmosphere of Mars has also received an important advance by the work of Campbell at Mount Hamilton. Although it is not proved that Mars has no atmosphere, for the existence of some atmosphere can scarcely be doubted, yet the Mount Hamilton astronomer seems to have shown, with great conclusiveness, that it is so rare as not to produce any sensible absorption of the solar rays.

I have left an important subject for the close. It belongs entirely to the older astronomy, and it is one with which I am glad to say this observatory is expected to especially concern itself. I refer to the question of the variation of latitudes, that singular phenomenon scarcely suspected ten years ago, but brought out by observations in Germany during the last eight years, and reduced to law with such brilliant success by our own Chandler. The north pole is not a fixed point on the earth's surface, but moves around in rather an irregular way. True, the motion is small; a circle of sixty feet in diameter will include the pole in its widest range. This is a very small matter so far as the interests of daily life are concerned. But it is very important to the astronomer. It is not simply a

motion of the pole of the earth, but a wabbling of the solid earth itself. No one knows what conclusions of importance to our race may yet follow from a study of the stupendous forces necessary to produce even this slight motion.

The director of this new observatory has already distinguished himself in the delicate and difficult work of investigating this motion, and I am glad to know that he is continuing the work here with one of the finest instruments ever used in it, a splendid product of American mechanical genius. I can assure you that astronomers the world over will look with the greatest interest for Professor Doolittle's success in the arduous task he has undertaken.

There is one question connected with these studies of the universe on which I have not touched, and which is, nevertheless, of transcendent interest. What sort of life, spiritual and intellectual, exists in distant worlds? We cannot for a moment suppose that our own little planet is the only one throughout the whole universe on which may be found the fruits of civilization, warm firesides, friendship, the desire to penetrate the mysteries of creation. And yet, this question is not to-day a problem of astronomy, nor can we see any prospect that it ever will be, for the simple reason that science affords us no hope of an answer to any question that we may send through the fathomless abyss. When the spectroscope was in its infancy it was suggested that possibly some difference might be

found in the rays reflected from living matter, especially from vegetation, that might enable us to distinguish them from rays reflected by matter not endowed with life. But this hope has not been realized, nor does it seem possible to realize it. The astronomer cannot afford to waste his energies on hopeless speculation about matters of which he cannot learn anything, and he therefore leaves this question of the plurality of worlds to others who are as competent to discuss it as he is. All he can tell the world is

> He who through vast immensity can pierce,
> See worlds on worlds compose one universe;
> Observe how system into system runs,
> What other planets circle other suns,
> What varied being peoples every star,
> May tell why Heaven has made us as we are.

THE ASTRONOMICAL OUTLOOK

AS RELATED TO THE PERFECTION OF OUR INSTRUMENTS AND METHODS OF OBSERVATION

PROFESSOR C. A. YOUNG

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PREDICTION is always hazardous, especially so in scientific matters. The unexpected is happening continually, as, for instance, in the discovery of the Röntgen rays, which has so transformed our views of the range of radiant energy. And yet the growth of science is, on the whole, an orderly evolution. The germs of the future are now present in various stages of development, and many of them so far advanced that we can already form some idea of what the product is to be.

Or, to put it differently, we are situated somewhat like persons standing on a little eminence

and overlooking a widely extended landscape. The nearer objects are for the most part conspicuous, though some are hidden by intervening obstacles. A little farther away things are less clearly seen, and all the remoter features are veiled in haze or shadow, or simply lost in the distance. Of all the various roads that lead forward from the observer's station only a few can be followed far by the eye; but some of the great highways are marked, and at the same time partly hidden, by lines of foliage and artificial structures, while of others glimpses are here and there attainable. So, as we try to penetrate the future of our science, a small portion of what lies nearest appears reasonably distinct, and we feel confident that sturdy persistence in following certain paths in which astronomers are now treading will carry them well forward into regions now visible but dimly, if at all. We know well, also, that very likely some most wonderful things lie close at hand, as yet undreamed of, and we have no idea how soon, or on what road they may reveal themselves.

But in some vital respects our figure fails. Astronomers do not overlook a wide and open valley, but rather from the foothills of a mountain range, look upward into mists and clouds, and every path soon disappears into obscurity, except where here and there sunlight breaks through. Some of these paths doubtless end at the foot of precipices which cannot be scaled, and

others lose themselves in morasses or glaciers; but some will lead the fortunate traveller to clearer light and air, and to gardens of rich fruit; for the heights of science are not, like earthly mountain-tops, barren and icy, but clothed with verdure and bathed in the light of heaven, where one breathes untainted air and enjoys most glorious prospects. But always before him rise summits more lofty, more inaccessible and more mysterious yet; for the highest attainment is, after all, only progress towards the unattainable infinite, and that which lies before bears always an increasing ratio to that which has been left behind.

Perhaps the first question which offers itself is, What advances are likely to be made in the methods and instruments of astronomical investigation? Can we hope soon to acquire new instruments of research relatively as powerful as those which the past has given us—instruments which, like the telescope and spectroscope, will open new and unknown regions hitherto hopelessly inaccessible? It is hardly safe to prophesy, but one is certainly warranted in saying, Why not? The discovery of new forms of radiant energy, like the Röntgen and Lenard rays, makes it conceivable that very possibly similar radiations may come to us from the heavenly bodies, and that before very long we may be in possession of apparatus which will enable us to detect those rays and to read the records they are sure to bring if they really reach us.

The undoubted—possibly the word is a little too strong—the, at least, more than probable connection between solar disturbances and our own magnetic storms, as well as the phenomena of comets' tails, makes it almost certain that magnetic and electric stresses and displacements prevail in interplanetary space; and, if so, the ability to detect and measure them would add greatly to our knowledge. As yet, no doubt, our instruments are inadequate to such studies, but they need not always be so.

Then it is not unreasonable, I think, to expect that we shall ultimately, and perhaps before many years, be able to measure the heat received from the stars and planets, and so to reach some knowledge as to their temperature and physical conditions. If we were now able to do this, certain important problems as to Mars might be summarily settled.

But even if no absolutely new instruments are soon invented, much is to be expected from the improvement of those we have. I see no reason why the power of telescopes may not be greatly increased in the near future. Some authorities, indeed, maintain that the limit of size has nearly been reached, and that instruments much larger than the Yerkes telescope can never be made satisfactory on account of the distortion of the object-glass caused by its own weight. But in this greatest of all telescope lenses the flexure is so slight as to be barely perceptible, and even in one of twice the diameter it need be nothing very

serious. The case differs immensely from that of a reflector. So far, however, as the mere ability to *see things* goes, it may well be doubted whether any great gain will follow mere increase of size, unless the new giants are to be mounted at places where the atmospheric conditions are far more perfect than at most of those hitherto occupied.

But the cry of the spectroscope and the photographic plate is always, "More light!" With telescopes such as are likely to be made within the next fifty years the astronomer will have at his disposal three or four times as much light as we are now able to command. The smaller stars will be brought within the range of spectroscopic study, and more subtle details in the spectra of the larger ones can be dealt with. And if photographic plates are correspondingly improved, it is difficult to say what could not be done in the way of instantaneous pictures of the heavenly bodies. If an impression could be obtained in a hundredth of a second, a great part of the exasperating atmospheric difficulty would be evaded, since, for so short a time as that, the air is often practically quiet, even when it is in an extremely bad condition for visual observation.

But, on the whole, increase in the size of telecopes seems now to be less important than the improvement of their optical qualities. Our present object-glasses, though wonderful products of the artist's skill, are very far from ideal—

hardly more, indeed, than a mere "first approximation" to absolute perfection. The fault is not with the optician, but in the material with which he has to deal.

The kinds of glass hitherto at his disposal are such that it is impossible to make from them lenses which will bring to the same focal point more than *two* differently coloured rays of the spectrum. If, for instance, the red and blue are perfectly united, then the green rays will come to their focus nearer to the lens and the violet farther away. In the best of the great telescopes now existing, therefore, the image of a bright object is surrounded by a strong purplish halo, which to the uninitiated appears very beautiful, but which to the astronomer is an abomination, because it makes it difficult to see small objects near the bright one, and seriously injures the definition of details upon the disk of a planet.

Within the past few years, however, the German manufacturers at Jena, working with a government subsidy, have been able to produce new kinds of glass which, properly combined, gives lenses free from this fundamental defect and have enabled their opticians to obtain unprecedented perfection in the construction of microscopes. Hitherto it has not been found practicable to supply disks of large size sufficiently homogeneous for telescope lenses and at the same time of a quality to resist the atmospheric hardships to which such lenses are necessarily exposed. But progress is constantly making. A

number of small telescopes from five to eight inches in diameter have already been constructed which are said to be very fine; and an English firm now advertises its readiness to supply "photo-visual" object-glasses as large as twenty inches in diameter.*

The peculiar name is given to indicate that these new lenses bring the rays which are specially effective in photography to the same focus as those which chiefly affect the eye, so that such a telescope is equally useful for both photographic and visual observations.

It may be that the new century is to bring in a new era in telescope-making, and that the

* It may be permitted here, I hope, to refer to the heavy loss which astronomy has lately suffered in the dying out of our great American telescope-makers, the Cambridge Clarks, the father and his two sons, who, during the last twenty-five years, have made more great object-glasses than all the other opticians of the whole world. Among their productions are the largest lenses of all, now mounted at the Lick and Yerkes observatories. Others, perhaps, may have possessed a profounder knowledge of optical mathematics, and perhaps an equal skill in the working of optical surfaces to theoretical curves, but none, I think, have had so ready a perception of just the right and best thing to do in order to overcome or evade the difficulties caused by slight imperfections in the material, such as are sure to be encountered in even the best specimens of the glass-founder's work. None certainly have surpassed them in the excellence of their finished lenses.

We still have opticians, however, who are following hard in their footsteps and have the advantage of the experience of their predecessors; we may well hope, therefore, that our country will yet be able to retain her pre-eminence in this important line of scientific art.

instruments to be used by the coming generation of astronomers will surpass in perfection our present ones as much as our new "apochromatic" microscopes excel those that our fathers worked with.

It is unquestionable that photography, which during the last twenty years has come forward so rapidly as a means of astronomical investigation, is to become still more important. Already there are immense fields in which it has not only replaced visual observation, but has gone far beyond the possibilities of vision, as, for instance, in the study of stellar spectra, and in the picturing of comets and nebulæ. But there are other fields in which it cannot yet at all compete with the eye of a good observer, as in the study of the details of a planet's surface, the measurement of close and difficult double stars, and in the so-called "observations of precision," hitherto made with meridian circles, transit instruments and other instruments of the same general class. The time is surely coming, however, and may be near at hand, when photography will take possession of these regions also. There is no reason in the nature of things why it may not be possible with improved plates and methods of development, to photograph everything that the eye can see with any instrument, and that more quickly than the eye can see it, thus securing a record that is permanent, authentic and free from the personal bias of imagination and hypothesis, which so seriously impairs the authority of many

ocular observations. This is not to be taken as a prediction that such ideal photographic perfection will soon, or ever, be actually attained; but if it is even approached the whole aspect of observational astronomy will be changed: the human retina* will have been practically supplanted by the photographic film.

Even more important, from some points of view, is the probable, or at least possible, development of astronomical mathematics. The astronomer is now confronted with numerous problems relating to the motions of groups of bodies under their mutual attraction, and while these problems are in their nature prefectly determinate and capable of solution, we have as yet no mathematical methods able to deal with them in a satisfactory manner. We may at least hope that the reproach will be removed before very long; that some new functions or methods may be found which will increase our powers of computation as greatly as did the invention of logarithms and of the calculus. It is true that the want has been pressing for nearly two hundred years and that failure has followed failure in the attempt to supply it. Doubtless, therefore, we ought not to

* One wonders sometimes whether there cannot be found some way to exalt the sensitiveness of the retina itself; some drug, for instance, that will for a short time so increase the power of seeing a faint object as virtually to give, for the time being, the advantage of a larger telescope. It is very tantalizing to be able barely to see a faint object but not clearly enough to measure it—a very common experience of every observer.

be too sanguine of any immediate success. Still, mathematical science has of late been making such great advances that it cannot be unreasonable to expect new and decisive conquests in this region. Until we have some such new methods and appliances, progress in dealing with the motions of star-clusters and of the great stellar system must be slow and painful; indeed, the full completion of the theory of our own little planetary system cannot apparently be reached by our present resources, though it is true that the discrepancies between calculation and observation are now, for the most part, so slight that until our instruments and methods of observing are much improved they are of small practical account. It is only rarely that these outstanding discordances are such as to make it certain that the theory itself is distinctly inadequate.

At present it is only in certain rather infrequent cases, and with considerable difficulty, that we can reach the precision of a "tenth of a second of arc" in the determination of the absolute direction of a planet or of a star; and in measuring the slight annual *change* of direction of a star (upon which our determination of its distance depends) the limit of error is at least a third as great. From many points of view even such precision is wonderful; one-thirtieth of a second is only half an inch seen at a distance of fifty miles. But the stars are so remote that from most of them the great orbit of the earth around the sun

is a mere point compared with this, and for most of them their apparent drift across the heavens does not amount to as much as this in a decade. It will be necessary immensely to increase the precision and number of our observations before the requisite data can be obtained for attacking many of the most important of the problems now opening before us. The observations of the great astronomers to come must as much exceed in accuracy the best of those we are now able to make as those of Bessel do those of Tycho. Science and art must go hand in hand; the mathematician, the optician, the mechanician and the indefatigable observer must all co-operate to the utmost of their ability, if we are to penetrate much farther with our knowledge of the stellar systems. At present we have only a few approximate results as to the distances and motions of the stars, their real magnitudes and personal peculiarities, and there can hardly be a doubt that the coming century will bring an immense expansion of human knowledge in these directions. The "Theory of the Stellar Universe"—what a field of study as compared with the "Planetary Theory," or the still narrower "Lunar Theory," each of which has engaged the attention of the ablest astronomers for long centuries! Truly horizons widen as we rise.

When we come to consider in order our prospects with respect to the "pending problems of astronomy," we naturally look first at the earth itself and the astronomical questions that

relate to it. The last few years have brought sure knowledge of a minute periodical shift of her axis and a corresponding displacement of the poles upon the surface of the globe. So far as the accuracy of our present observations can decide, this shift appears to be nearly regular; and yet theory would rather indicate that for various reasons it must be more or less irregular, and accompanied by corresponding changes in the rate of rotation or length of the day. It is to be hoped that before very long we may become able to detect the presence and amount of such irregularities if they really exist, and it is not to be disguised that some anxiety is felt lest it should be found that we are already near the limit of accuracy in astronomical prediction—actually approaching a boundary which cannot possibly be overpassed. For if the earth, our standard measurer of time, "goes wild" to some appreciable amount, it is clearly impossible to predict astronomical events within time-limits closer than the extent of her vagaries—unless, indeed, some other time-measurer can be found, steadier and more to be trusted, to take her place.

Doubtless, also, the years to come will correct our knowledge of the dimensions of our globe and of its mass and density. At present our estimate of the distance between any two "well-determined points" on opposite hemispheres—say, for instance, between the centres of the domes of the observatories at Washington and the Cape of Good Hope—is uncertain by at least a thou-

sand feet; the earth's mass in tons is still in doubt by fully one or two per cent. The limits of error have been much diminished by the geodetic operations and gravitational experiments of the last twenty-five years, but there remains abundant room for improvement.

As regards the moon, the theory of her motions has not yet by any means reached finality, and numerous able mathematicians are still at work upon it. It is hardly likely, however, that any great discovery is to be made in this line of research. Observation and theory will doubtless draw into closer accordance, until at last their discrepancies will be only such as can fairly be attributed to the inaccuracies of our standard time-keeper—the slight irregular changes in the earth's rotation due to occasional geological paroxysms, such as earthquakes and its consequent acceleration or retardation by a few thousandths of a second of time.

The application of photography has already added much to our knowledge of the lunar surface, and is certain in a few years to give us charts of the hemisphere which is visible to us far exceeding in accuracy our maps of any but selected regions of the earth. Two large lunar atlases are now being published—one by the Paris Observatory and the other by the Lick; a third, on a much larger scale than either of the other two, but based on the same photographic material, is proposed to be issued at Prague. Comparison of these authentic records of the

moon's present state with those that are to be obtained hereafter will surely settle the interesting questions relating to changes in progress upon the surface of our satellite. Doubtless, also, the improved instruments for the measurement of heat and other radiations will make our understanding of its physical conditions vastly more sure and definite.

While we are now certain that the average temperature of the moon is very low, we know nothing definite as to its range, nor how hot the surface rocks may become during the moon's long day of unclouded sunshine, lasting more than three hundred hours.

As to the moon's averted face—the side never yet seen from the earth—there is no prospect that the future will do anything for us. There is no reason to suppose that it differs in any important respect from the face we see and study; probably, however, men will never know; and yet more than once in the history of science somewhat similar negative predictions have been discredited.

Solar astronomy promises rapid advance. Even with our present means of investigation, facts and data are fast accumulating which, by the mere lapse of time, will furnish an answer to many of the most important questions now open, such as those which relate to the imagined influence of the planets in causing disturbances of the sun's surface and the effect, if any, of such disturbances upon our own terrestrial affairs.

Lately, also, it has become pretty clear that in the study of solar physics we have to do with conditions not permanent, but transitional; that certain phenomena which have long most perplexed us, like the peculiar acceleration in the motion of the sun's surface in the regions near its equator, are mere "survivals" and have their origin and explanation not in causes now operating, but in the far-distant past. We study in the sun a process rather than a thing; or, if a thing, one that is not permanent and stable, but in a state of flux and change, and this guiding thought, newly acquired, wili probably aid greatly in the interpretation of the facts of observation. Doubtless, also we shall by-and-by have instruments which will enable us to follow out in a way now impossible the daily and hourly changes in the solar radiation and co-ordinating these results with those of visual and photographic observation, we shall gain an insight into the now most puzzling phenomena of sun-spots and prominences. Then, too, the more detailed study of the solar spectrum under various conditions and its comparison with the results of laboratory work are sure to throw light in both directions—to give us on the one hand a better understanding of the sun and its conditions and on the other to make more intelligible the nature and behaviour of molecules and molecular forces. It is to be hoped, also, that the faithful observation of eclipses will in time solve the numerous and intensely interesting problems pre-

sented by the sun's mysterious corona—if, indeed, some new mode of observation does not soon remove the restrictions which now confine our observations to such rare and precarious opportunities.

Turning to the planetary system, we see a wide field for the increase of our knowledge, and an encouraging probability of progress, both through the patient use of our present means of investigation, and still more by the aid of the expected improvements in instruments and methods.

Mere persistence in the old ways is certain to give us ultimately a much exacter knowledge of the dimensions and motions of the system, and may very likely be able to throw light upon certain perplexing problems presented by some slight apparent anomalies which as yet seem to be inexplicable on the existing theories of gravitation. Possibly the power of the new mathematics may show them to be merely apparent and perfectly reconcilable with that theory (as has often before happened in similar cases); but it may well be, and in fact is rather likely, that our "law of gravitation" as at present formulated is only an approximation to a complete and perfect statement—an approximation so near the truth, indeed, that its representation of the facts is about as exact as our present means of observation and computation. When anomalies crop out, we are as yet doubtful whether to

attribute them to errors of observation, inaccuracy of the computer, or real error in the fundamental statement of the "law."

Thus far we have no satisfactory physical explanation of the mysterious force which produces the so-called "attraction" between masses of matter, however remote from each other, nor does any valid reason appear why it should vary "inversely as the square of the distance" between them. It is simply a fact of observation that such a force exists, and that it follows the law assigned with remarkable if not absolute precision. It remains for the future to show just how it is related to the other forces of nature, to attractions and repulsions which we designate as chemical, electric, and magnetic, and to the energies transmitted by the various forms of radiation. It is almost certain that these are all consequences of the constitution of the so-called "ether"—the hypothetical substance that fills all space, indispensable to the physicist, and yet almost inconceivable in the nearly self-contradictory properties which have to be assigned to it in order to account for its behaviour and functions. We do not mean to intimate that astronomy alone will ever be able to solve the difficult problems which are suggested in this connection, but only that the motions of the planets and the stars will throw light upon them, and will themselves find elucidation as the results of physical research gradually clear up the origin and theory of the "pulls and pushes"

which prevail throughout the universe of matter.

The progress of our knowledge as to the planets themselves and what we may call their personal peculiarities will probably depend largely upon the improvement of our means and methods of observation. The grotesque discrepancies and contradictions between the reported results of different observers now throws more or less doubt on the conclusions of all. And yet the unquestionable gains that have accrued within the last twenty years are very encouraging. It seems to be fairly proved that the two inner planets imitate the behaviour of the moon in keeping always the same face towards the sun, and the observations of the elder Herschel and others, which indicate a similar peculiarity in some of the satellites of Jupiter and Saturn, have lately received direct confirmation. We may now, therefore, with reasonable confidence, assume the theory of "tidal evolution" as a guiding clue in our study of the development of the planetary system.

As to the nature and interpretation of the markings seen upon the surface of the different planets, much uncertainty still remains, which time may be expected to remove. If we could reasonably adopt the reports and descriptions of some single one of the observers who have devoted themselves to the study, we might logically reach pretty definite conclusions. But until the agreement between observers is improved we can only hesitate and wait for more

harmonious information. When at last we get photographs as large and distinct as the drawings which observers furnish—photographs made at different times and stations—we shall be better able to discriminate between the permanent and the transient; between markings that are really geographical and those which are only phenomena of the planet's atmosphere; between changes that are merely apparent and those that are real, significant, and important—such as are due to geographical changes, to the progress of the planet's seasons, or possibly to the consequent growth and decay of vegetation, as in field and forest. And in the study and interpretation of the visible phenomena our successors will be aided by the new appliances for the measurement of heat and other radiations which they may be expected to have at their disposal. As to the discovery of intelligent inhabitants, few astronomers, I think, seriously expect it, or even consider it within the range of probability; still less that we shall ever be able to enter into communication with them, even if assured of their existence.

Doubtless a multitude of new asteroids will be found, and possibly some new light will be thrown on their origin. It may be, too, that other planets may be discovered—one or two, perhaps, outside of Neptune, and possibly some small bodies between Mercury and the sun.

The almost startling discovery of the little satellites of Mars and the new pigmy of Jupiter's

system make it not wholly improbable that others may not yet be found, especially in the systems of Saturn and Neptune. But there seems very little likelihood that satellites of Mercury or Venus will ever be discovered, or any new attendant of the earth.

What is to be the progress of our knowledge in respect to meteors and comets it is not easy to foresee. As regards their orbital motions there is perhaps not much to expect, because our present theory seems to be reasonably complete. And yet it seems *a priori* not unlikely that the force which operates to produce the tails of comets should have some influence upon their movements; and such a phenomenon as the persistent acceleration of Encke's comet suggests, at least, a possible necessity for farther refinements. Certainly greater precision of observation is needed to enable us to pronounce with certainty upon the questions of cometary identity which are continually arising. And these questions are of extreme importance in their bearing upon the theory of the origin of comets and their relations to our system. We may earnestly hope, therefore, that the surely growing accuracy of observation and computation will throw light upon this problem.

As to the physical constitution and nature of comets, we may, perhaps, expect a great improvement of our knowledge just because our present ignorance is so great. Many facts, of

course, are well known, and some of those best known are the most mysterious of all. Conjectures are numerous, but all seem to be more or less unsatisfactory and in conflict with some of the observed data. We can as yet only guess at the forces which produce the peculiar phenomena that accompany the approach of a comet to the sun, and develop the magnificent trains of luminous matter which have always excited the wonder, and often the terror, of mankind. Photography has already made great progress in registering these phenomena, and bringing out features invisible to the eye, but apparently of high significance. It will certainly go much farther in the future. And investigations in the physical laboratory will almost certainly hereafter render intelligible much of the behaviour that is now so perplexing. The subject is a most fascinating one, and certainly will not be neglected.

And now that the meteors are reckoned as astronomical bodies, they also are receiving careful attention, and our knowledge of their relation to comets and to the universe is rapidly growing. We may well hope that during the coming century this new domain of astronomy, annexed only some thirty years ago, will become a fruitful and important department of the science; and that, even if time should not wholly make good the bold speculations of Sir Norman Lockyer and others, who see in meteoric swarms the very essence and substance, not of comets

only, but of nebulæ and many stars, and find in meteoric collisions the explanation of a whole host of the most interesting and beautiful of astronomical phenomena.

As to the stars, it is sure that the coming century will bring an immense increase of knowledge. It will be rash to endeavour to predict just along what lines and to what extent the development will take place; the problems are so numerous and so intricate, and their successful investigation depends so much on the improvement of our means of observation and calculation, that no one can say which will first be solved. As in the case of the sun, mere lapse of time will settle many questions. It will accumulate knowledge as to the motions of the stars, and of the solar system among the stars, and also of the motions of the components of double stars, of multiple stars and clusters; and will ultimately determine with certainty whether the same law of gravitation which rules the planetary system prevails also in stellar space. It will give us data as to the variability of the light of stars, and probably will clear up the causes of it. It will ascertain how, if at all, the nebulæ change their form and brightness, and how, if this really be the case, stars develop within them, and the nebula becomes a cluster.

But how rapidly this knowledge will be gained must, of course, depend on many things; one dares not prophesy. And yet it is certain that the astronomers of the century to come will

stand on a plane above our own, with instruments, appliances, and methods more delicate, more powerful, more far-reaching than ours; and it is only reasonable to anticipate for the twentieth century an accelerated advance in every science. Astronomy among the rest,—the oldest, most glorious of all, will surely maintain her place in the triumphal march.

PHOTOGRAPHY OF THE SKIES

GEORGE ILES

[From "Flame, Electricity and the Camera," copyright by Doubleday, Page & Co., New York.]

DR. JOHN W. DRAPER, of New York, who was the first to portray the human face in the camera, was also the first to photograph a heavenly body. In March, 1840, he succeeded in taking pictures of the moon, which were fairly good, considering the imperfection of his instruments. Five years later Professor G. P. Bond, at Harvard Observatory, obtained clear portraits of the moon with a fifteen-inch refractor, and in so doing launched his observatory on a career of astronomical photography which to-day gives it the lead in all the world. From 1865 to 1875 Mr. Lewis M. Rutherfurd, of New York, took photographs of the moon which for twenty years were unrivalled. At present the moon is the best photographed of all celestial objects, and yet Professor Barnard says that the best pictures thus obtained come short of what can be seen with a good telescope of very moderate size. Thus far minute details of the surface are beyond the reach of photography, but its accurate delineation of the less difficult features is of the highest value.

"The photography of the surface features of

the planets," adds this observer, "is in an almost hopeless condition at present; yet much may be expected when an increased sensitiveness of the plates has been secured." No plate as yet produced is fully responsive throughout the whole range of the telescopic eye. Clearly enough, the draughtsman has not been ousted from every corner of the observatory as yet, although, in most of its tasks, his services have long ceased to be required; in one of them the embarrassment of the camera is not a lack but an excess of light. Professor Janssen of the observatory at Meudon, near Paris, long ago succeeded in making the best photographs of portions of the sun's surface; he has always used the wet-plate process, which, from its slowness, gives the best results with the intense solar beam.

Just at the turning point between old and new methods of recording the phenomena of the sky, there was a contrast between them which was decisive. On July 29 1878, a total solar eclipse was so widely observable throughout the United States that forty to fifty drawings were made of the corona, duly published by the United States Observatory, Washington, two years afterward. Says Professor Barnard: "On examination scarcely any two of them would be supposed to represent the same object, and none of them closely resembled the photographs taken at the same time. The method of registering the corona by free-hand drawing under the conditions attending a total eclipse received its

death-blow at that time, for it showed the utter inability of the average astronomer to sketch or draw under such circumstances what he really saw." Compare the pencil with the camera in one of its recent achievements. On January 22, 1898, Mrs. Maunder with a lens only one and a half inches in diameter, secured impressions of swiftly moving coronal streamers about five million miles in length. It is evident enough that the pencil cannot compete with the camera in depicting the extremely brief phenomena of an eclipse, and it is also plain that an instrument of moderate size and cost is quite sufficient for good work.

Often the images of the telescope are not fleeting, and remain visible quite long enough for a draughtsman to catch their outlines; but other circumstances than those of time forbid the use of his pencil. Professor E. E. Barnard has taken observations at the Lick Observatory when the thermometer has stood at —32° C. At such a temperature a camera may be used, while to employ a pencil is out of the question.

In many tasks, where extremes of cold or heat do not trouble him, the astronomer is glad to avail himself of the quickness of the sensitive plate, which so far transcends the celerity of the eye. If in its rapidity of response a quick plate is superior to the retina, it has the further advantage of being exempt from fatigue. Light much too feeble to excite vision can impress an image on a sensitive plate if it is given time

enough. During four hours ending at two o'clock in the morning, M. Zenger has taken photographs of Lake Geneva and Mont Blanc when nothing was perceptible to the eye. Turned to the heavens, this power to grasp the invisible brings into view a breadth of the universe unseen by the acutest observer using the most powerful telescope. Let the lenses of such an instrument be directed to a definite point in the sky by accurate machinery, and they will maintain their gaze with accumulating effect upon a sensitive plate through all the hours of a long night, and, if need be, will renew their task the next night, and the next.

In this work the utmost mechanical precision is imperative. Professor E. E. Barnard says that if the motion of a guiding clock varies as much as one-thousandth of an inch during an exposure of from three to eight hours, the images are spoiled and worthless. It was only after repeated failure that mechanicians were able to make a clock sufficiently accurate to keep a star image at one fixed point on a plate. Steadily caught at one unchanging place, a ray, however feeble, goes on impressing the pellicle of a plate, minute after minute, hour after hour, night after night, until at last, by sheer persistence, the light from a star or a nebula too faint to be detected in a telescope imprints its image. Some images have been obtained as the result of twenty-five hours' exposure during ten successive nights, so as to get impressions from as near the zenith

as possible, where atmospheric disturbances work least harm because atmospheric paths are there at their shortest. Myriads of heavenly bodies have thus been added to the astronomer's ken, which, without the dry plate, would probably have remained unfound forever.*

When Dr. Maddox was busy stirring together his bromides and gelatin he did not know that from his bowl the universe was to receive a new diameter; but so it has proved. The invention of the telescope marks one great epoch in the astronomer's advance; another era, as memorable dawned for him when he added to the telescope a camera armed with a gelatin film. He gained at once the power of penetrating depths of space which otherwise would never have sped the explorer a revealing ray. And, remarkable enough, it is that to-day the first glimpse which the astronomer receives of a new orb is in the dark room, as he develops a telescopic plate which may have been exposed for hours. As the camera outranges the eye, in that very act it surpasses every task of depiction which the eye may dictate to the hand.

So efficient is the scouring of the heavens by the telescopic camera that to its plates is now resigned the search for those little worlds, or world fragments, known as asteroids. The hunt is simplicity itself. A plate is exposed in a camera, and directed by clockwork to a particular

* See a superbly illustrated article by Professor E. E. Barnard, *Photographic Times*, August, 1895.

point in the sky for two or three hours. Because the stars are virtually motionless in a time so short, they register themselves as tiny round dots. The asteroids, on the other hand, have an appreciable motion across the field of view, somewhat as the moon has, and so they betray themselves as minute but measurable streaks. On August 13, 1898, a streak of this kind disclosed to Herr Witt at the Observatory of Urania, at Berlin, that most interesting and important of all asteroids, Eros, about ten miles in diameter, which approaches the earth more closely than any heavenly body but the moon. It is expected that observations of Eros will enable astronomers to revise with new precision their computations of the distance of the sun and the planets. A faint streak similar to that observed by Herr Witt once told Professor Barnard that a comet had passed in front of his telescope —a comet so small and flimsy that only a photographic plate could see it. Early in 1899 Professor William Pickering thus discovered a new

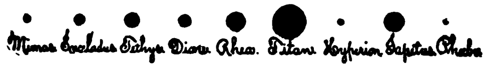

FIG. 87.

Satellites of Saturn. Phœbe, the ninth, discovered by Professor William Pickering.

satellite of Saturn, making its known retinue nine in number. This new moon made its appearance on four plates exposed with the Bruce

telescope at Arequipa, in Peru. Its light is so faint that no telescope in existence is powerful enough to disclose the tiny orb (Fig. 87).

Where direct vision is easy, the camera enables the photographer to save time in an astonishing way. Professor Common's photograph of the moon, taken in forty minutes, rewarded him with as full detail as had four years' work with the telescope and pencil. Often an image seen only in part in the telescope is completed with wonderful beauty in the camera. The streaming tail of a comet is frequently doubled or trebled in length as it imprints itself upon the gelatin plate. Brooks's comet of 1893, in one of its photographs taken with the Willard lens at Lick Observatory, showed its tail as if beating against a resisting medium, and sharply bent at right angles near the end, as if at that point it encountered a stronger current of resistance. Many nebulæ, those of the Pleiades especially, appear in much greater extent and detail in a photograph than to an observer at the eye-piece of a telescope. Their rays are particularly rich in the vibrations which affect the sensitive plate, but to which the eye is irresponsive.*

More than once a word has been said about the unsuspected worth of the incidental; celestial photography supplies a capital illustration. In 1882, at the Cape of Good Hope, when the great

* Address by Professor E. E. Barnard as vice-president of Section A,—mathematics and astronomy,—American Association for the Advancement of Science, 1898.

comet of that year appeared, it occurred to Dr. Gill, the director of the observatory, that it might be possible to photograph it. To the telescope, pointed at the comet, a small camera was accordingly attached. After a short exposure the plate was developed and the image of the comet came into view. So far as is known, this was the first comet ever photographed. The plate, moreover, showed not only the comet which had been sought, but also stars which were unsought, and that were quite invisible in the telescope (Plate XVI). From their images, thus unwittingly secured, came the project of a new map of the heavens, which should reveal its orbs to the limit of a plate's impressibility. With the Observatory of Paris as their centre, astronomers throughout the world are now engaged upon a chart of the sky which will contain at least twenty million stars. In future generations a comparison of the pictures now in hand with pictures of later production will have profound interest. Stellar changes ot place and nebular alterations of form will indicate the laws of the birth, the life, the death of worlds.

At the close of the year 1899 there were stored at Harvard Observatory 56,000 plates depicting the heavens during every available night beginning with 1886. Doublet lenses, of much wider field than the single lenses usually employed, have been chosen by Professor E. C. Pickering, the director, for this work. Thanks to their use, certain of the plates have been found

PLATE XVI.

PHOTOGRAPH OF COMET BY DR. DAVID GILL, 1882

With incidental portraiture of stars invisible in the telescope

In passing from the colours of the solar spectrum to its many minute interruptions, "the new astronomy" began. As photographed by Professor Rowland upon sheet after sheet for a total length of forty feet, the spectrum of the sun is crossed by thousands of dark lines. The interpretation of the most conspicuous of these lines by Bunsen and Kirchhoff in 1859, marks an epoch in the study of the heavens. Let us approach their explanation by a simple experiment. If we sing a certain note upon the wires of an open piano, just that string will respond which, if it were struck, would utter that note. Precisely so when we pass from vibrations of sound to those of light; a vapour when cool absorbs by sympathy those waves of light which, if it were highly heated, it would send forth. Hence the dark lines in the solar spectrum tell us what particular gases, at comparatively low temperatures, are stretched as an absorbing curtain between the inner blazing core and outer space. To choose a convincing example: when the spectrum of the sun and that of iron are compared side by side in the same instrument, bright lines of the iron coincide with dark lines of the solar spectrum.

The tints and lines of a spectrum, whether from the sun or a star, disclose not only the character but the consistence of the elements which send them to the eye or to the photographic plate. Hydrogen, for example, when it burns at ordinary pressures, as it may in the simplest laboratory experiment, emits a spectrum of bright lines

crossed by sharp thin lines of darkness. These bright lines, when the gas has high pressure, broaden out and become almost continuous, so as to resemble those emitted by a glowing solid. Hence an astronomer is told by one particular spectrum that it comes from a star having a highly condensed gaseous core, while another spectrum betokens a true nebula—a vast body of gas aglow in extreme attenuation. A spectroscope, therefore, reveals not only what a heavenly body is made of, but also the physical condition in which its substances exists, whether as a solid, a liquid, or a gas.

The lines in a stellar spectrum are liable not only to be broadened out, but to be shifted from their normal place, and this shifting has profound significance, according to a principle first announced by Christian Doppler in 1841. If a star is at rest, relatively to the earth the tints and lines of the elements aglow on its surface will have positions in its spectrum as changeless as those due to the iron or the sulphur aflame on the chemist's tray. But if the star is moving towards the earth, or away from it, the spectral lines will appear a little to the right or left of their normal position, and in so doing disclose the rate of approach or recession. To understand this we have only to enter the field of acoustics. Suppose that a listener takes up his post midway between two railway stations somewhat distant from each other. As a locomotive approaches him let us imagine that its whistle is

blown continuously. To the engineer on the footboard the whistle has a certain note; to the listener who is standing still the whistle has a somewhat shriller note, because the motion of the engine towards him has the effect of shortening the sound waves, and shrillness increases with the shortness of such waves—with the greater number per second he hears. If all the engines of the line have whistles exactly alike, a listener with his eyes shut can easily tell whether it is a freight-train that is advancing or an ordinary express, or a "limited" running at fifty miles an hour; the quicker the train, the shriller the sound of its approaching whistle (Fig. 88). Sir William

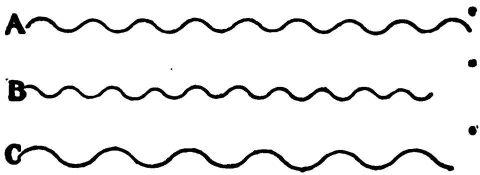

FIG. 88.

A, waves between two points at rest relatively to each other.
B, waves between two points at a shortening distance apart.
C, waves between two points at a lengthening distance apart.

Huggins, the pioneer in applying this principle to reading stellar motions, adopts a parallel illustration: "To a swimmer striking out from the shore, each wave is shorter, and the number he goes through in a given time is greater than would be the case if he stood still in the water."

Let us now return to the sister phenomena of light. At one end of the visible spectrum the violet rays have about half the length of the red rays at the other end of the scale; accordingly about twice as many violet as red rays enter the eye in a second. Let us imagine a star like Betelgeux, which, at rest, would emit red rays solely. If such a star were to dash toward the earth with the speed of light, 186,400 miles a second, its rays would be so much shortened as to be halved in length, and the star would appear violet—its characteristic lines and hues showing themselves at one extreme of the visible scale instead of at the other. Of course, no star moves toward the earth with more than a small fraction of the speed of light, and yet so refined is the measuring of the displacement of spectral lines that a motion toward the earth of somewhat less than one mile in one second can be readily determined. In the case of Betelgeux its movement toward the earth is known to be seventeen and six-tenths miles a second, about one eleven-thousandth part of the velocity of light, the displacement of its red lines toward the violet end of the scale being about one eleven-thousandth part of the whole length of the spectrum. If, in a contrary case, a star is receding from the earth, its spectroscopic lines will be shifted toward the red end of the scale, just as a locomotive whistle falls to a lower pitch as the engine moves away from a listener standing still. By this method Gamma Leonis is known to be

travelling away from us at the rate of twenty-five and one-tenth miles a second. In this unique power of detecting motion in the line of sight, the spectroscope when furnished with a sensitive film enormously enhances the revealing power of the telescope.

The sun was, of course, the first heavenly body to have its spectrum caught on a sensitive plate. In 1863 Dr. (now Sir) William Huggins attempted to photograph the spectrum of a star. He obtained a stain on his plates, due to the spectra of Sirius and Capella, in which, however, no spectral lines were discernible. In 1872 Dr. Henry Draper, of New York, obtained a photograph of the spectrum of Vega, in which four lines were shown; this was the first successful picture of the series which Dr. Draper gave to the world during the following ten years. Since his death, in 1882, Mrs. Draper has established the Draper Memorial at Harvard Observatory, for the continuance of his labours on an extended scale. The photographs by this memorial owe much to the Vogel method, by which the plates are sensitized for green, red and yellow rays. Were this sensibility to colour still further increased, the photographs of stellar spectra would tell a yet fuller story than they do to-day. Owing to irregular atmospheric currents, the image of a star dancing around the narrow slit of a spectroscope may elude even a practised observer. Photography, with its summation of recurrent impressions, gives a perfectly uniform image of the composite type

which Mr. Galton introduced in human portraiture. That image, for all its minuteness, may bear a most informing superscription.

In the northwestern sky one may observe the constellation of the Charioteer—to most advantage in April or May. At Harvard Observatory, in 1889, it was remarked that a spectrum from a star in that constellation, Beta Aurigæ, varied from night to night in a singular manner. The cause was found to be that the light comes, not from a single star, but from a pair of stars, periodically eclipsing each other, and having a period of revolution of slightly less than four days. In determining the rate of motion of these stars as one hundred and fifty miles a second, their distance from each other as 8,000,000 miles, and their combined mass as two and three-tenth times that of the sun, Professor Pickering regards the prism as multiplying the magnifying power of the telescope about five thousand times. To a telescope such a double star appears as but a single point of light; in a spectroscope each component star reveals its own spectrum. When the star is approaching the earth its spectral lines are shifted to the violet end of the scale; when the star is receding from the earth, its lines are displaced to the red end of the scale. In the case of Beta Aurigæ the change in the spectrum is so rapid that it is sometimes perceptible in quickly successive photographs, and becomes very marked in the course of an evening:

"Plate XVII illustrates this phenomenon. In

Fig. 1 the theoretical curve during December, 1889, is represented by the sinuous line, abscissas indicating times, and ordinates the corresponding separations of the components of the *K* line. The black circles represent the twenty-seven photographs taken during this month, their ordinates representing the result of a rough measure of the separation of the lines. In no case does the observed position differ from that given by theory by more than the accidental errors of measurement. Fig. 2 is a contact print from the original negative taken December 31, 1889, at 11*h.* 5*m.*, Greenwich mean time. Fig. 3 is an enlargement with cylindrical lenses of this same negative. Fig. 4 represents a still greater enlargement of the same negative, and shows the *K* line distinctly double; by shading one part of the photograph the strong line *a* to the left of *K* is also shown in the enlargement to be double. . . . Fig. 5 is a similar enlargement of a negative taken December 30, 1889, at 17 *h.* 6*m.*, Greenwich mean time, eighteen hours previous to Fig. 4. The lines here are single."*

This subtile means of detection is set upon the track not only of double stars, but on that of such a star as Algol, which is attended by a planet so large as to eclipse it almost wholly in a period somewhat shorter than three days.

"These binary systems, so different from any previously known, would in all likelihood have

* Henry Draper Memorial, Fourth Annual Report, Cambridge, Massachusetts, 1890.

been hidden for ages to come but for photography, because until that discovery was made there was no apparent reason for every-day examination of the spectrum of a star. Indeed, until then, when the lines were once carefully measured they were put aside by the observer as finished and definite records of the star's spectrum. These first results indicate that the components of Beta Aurigæ are separated by an angular interval of only one nine-hundred-thousandth part of a degree, a quantity so small that twenty years ago no one would ever dream of being able to measure it."*

New demands give the eye new refinements: the duplicity of the spectral lines of Beta Aurigæ was discovered by Miss A. C. Maury. Mrs. W. P. Fleming of Harvard Observatory has become so expert in detecting variable stars by their spectra that she recognizes them instantly among hundreds of other spectra on the same plate. And mark the value of these photographic spectra for subsequent investigation. Mrs. Fleming says: "While an astronomer with a telescope, be it ever so powerful, is at the mercy of the weather, the discussion of photographs goes on uninterruptedly, and is much more trustworthy than visual work, since, when a question of error arises, any one interested in the

* Address by Professor H. C. Russell, government astronomer, Sydney, to Section A,—astronomy, mathematics, and physics,—Australian Association for the Advancement of Science, 1893.

research can revise the original observation by another and independent examination of the photograph." During the eight years beginning with 1892, four stars of more than the ninth magnitude were added to the charts of astronomy; in every case the discoverer was Mrs. Fleming as she detected the spectrum of a new star in celestial photographs.

Professor J. Clerk-Maxwell was of the opinion that the rings of Saturn are simply aggregates of meteorites which preserve their outline by swift rotation. His belief has been verified by Professor Keeler at the Allegheny Observatory, his spectroscope proving that the inner edge of each ring moves more swiftly than the outer edge. If the ring were a solid body the reverse would be the fact, and the lines in its spectrum would be very nearly continuations of the lines in the spectrum of the central ball. So refined is this field of inquiry that the astronomer's reliance is upon a micrometer exquisite enough to measure a space of one ten-thousandth of an inch on a photograph.*

The latest chapter in the history of the solar spectrum has been added by Professor George E. Hale, director of the Yerkes Observatory. An ordinary spectroscope has a slit through which a narrow ray of light passes into a prism for dispersion. To this slit Professor Hale adds an-

* "Some Notes on the Application of Photography to the Study of Celestial Spectra," by James E. Keeler, *Photographic Times*, May, 1898.

other which permits only light of a single colour to reach his photographic plate. Because this light is of but one hue, pictures can be obtained of objects not to be photographed in any other way. Moving the apparatus at will, he secures photographs of the prominences around the edge of the sun, as well as of the whole surface of its disc. A visual examination of the prominences would require two hours, but pictures of them may be taken in two minutes. Many faculæ [bright spots], undiscernible by any other means, have been brought to view by Professor Hale's instrument, which he calls the spectro-heliograph. The device was suggested by Janssen as long ago as 1869; it was independently invented by Professor Hale in 1889.

The extension of disolosures by the camera in regions blank to the eye seems without bound. Beyond the violet ray of the solar spectrum extend vibrations which, though invisible, have been caught on photographic plates ever since the experiments of Scheele in 1777. Victorium, an element recently discovered by Sir William Crookes, has a spectrum high up in the ultraviolet region, which, therefore, can be studied only photographically. More than one element has made its first appearance to the chemist as he has observed the spectrum of the sun. Helium thus introduced itself long before its discovery in the atmosphere of the earth. Coronium, which appears in the solar corona, has been diligently

searched for, especially in the tufa of volcanoes, but thus far without assured results.

Toward the end of the spectrum, beyond the red, are invisible radiations which evaded capture until 1887, when Captain Abney secured an image from them on a bromide-of-silver plate. He maintains that in the use of plates sensitive to such ultra-visible rays, astronomers have a new means of exploring the heavens, and are free to enter upon a fresh chain of discoveries. To the stars already known it is in their power to add two classes as yet unseen—stars newly born or newly dead, whose temperatures in consequence are below the range of visible incandescence.

When light succeeded the pencil as a limner of nebulæ there was the keen interest that attaches to the calling of a new witness in a case before the highest court—a witness so much more observant and alert than any other, so absolutely devoid of bias or prejudice, that his evidence decides the verdict. For a century and more the nebular hypothesis of the universe, propounded by Kant and Laplace, had been vigorously debated by astronomers and physicists. The great telescopes of the two Herschels had enabled observers to descry nebulæ having the shapes which vast cloudy masses would assume in the successive phases of condensation imagined in the theory. Some were spherical in form, others were disc-like, yet others were ring-shaped, and the most significant outline of all, that of a spira, was also discerned. But when Lord Rosse's

great reflector was turned upon certain of these masses they were resolved into stars, and a good many critics said that, given telescopes sufficiently powerful, all nebulæ would in the same manner prove to be nothing else than stars. A few years afterward the spectroscope was employed by the astronomer, and soon it discriminated between seeming nebulæ, which are really star clusters, and true nebulæ, which are only the raw material from which stars are condensed. In the evening of August 29, 1864, the spectroscope, attached to a telescope, was for the first time directed to a nebula—the planetary nebula in Draco, by Dr. (now Sir) William Huggins. This is what he saw:

"The riddle of the nebulæ was solved. The answer, which had come to us in the light itself, read, Not an aggregation of stars, but a luminous gas. Stars after the order of our own sun, and of the brighter stars, would give a different spectrum, the light of this nebula had clearly been emitted by a luminous gas. With an excess of caution, at the moment I did not venture to go further than to point out that we had here to do with bodies of an order quite different from that of the stars. Further observations soon convinced me that, though the short span of human life is far too minute relatively to cosmical events for us to expect to see in succession any distinct steps in so august a process, the probability is indeed overwhelming in favour of an evolution in the past, and still going on, of the heavenly hosts. A time surely existed when the matter now condensed

into the sun and planets filled the whole space occupied by the solar system, in the condition of gas, which then appeared as a glowing nebula, after the order, it may be, of some now existing in the heavens. There remained no room for doubt that the nebulæ, which our telescopes reveal to us, are the early stages of long processions of cosmical events, which correspond broadly to those required by the nebular hypothesis in one or other of its forms."*

The first photograph of a nebula, that of Orion, was taken by Dr. Henry Draper on September 30, 1880. In the following March he took another in a little more than two hours, which, for nearly every purpose of study, was incomparably better than the drawing that had occupied Professor Bond for every available hour during four years ending with 1863. Better still is the photograph secured in but forty minutes with the Crossley Reflector at Lick Observatory, November 16, 1898. Dr. Isaac Roberts of Crowborough, in England, is a successful photographer of nebulæ, and his pictures are instructive in the extreme because he compares them with pictures of stellar systems; between the two he finds a connection strongly suggestive of derivation.

"To begin with, he shows a number of photographs of star regions in which the stars can be seen grouped into semi-circles, segments, portions of ellipses and lines of various degrees of curvature. Some of these groups are composed

* *Nineteenth Century*, June, 1897.

of stars of nearly equal magnitude; some of faint stars, also of nearly equal magnitude; while the distances between the stars are remarkably regular. Passing from these characteristics of stellar arrangement to photographs of spiral nebulæ, Dr. Roberts points out that the nebulous matter in the spirals is broken up into star-like loci, which in the regularity of their distribution resemble the curves and combinations of stars exhibited by photographs upon which no trace of nebulosity is visible. It seems, therefore, that the curvilinear grouping of stars of nearly equal magnitude gives evidence that the stars have been evolved from attenuated matter in space by the action of vortical motions and by gravitation. Exactly how the vortical motions were caused, or what has brought about the distributions of nebulosity in the spiral nebulæ, cannot be answered; but the marvellous pictures of Dr. Roberts establish the reality of the grouping, and furnish students of celestial mechanics with rich food for contemplation."*

"As Professor Bond drew the nebula of Andromeda with his eye at the best telescope he could command, he depicted dark lanes which come out in a photograph as divisions between zones of

* *Nature*, March 3, 1898.

A second volume of Dr. Roberts's "Photographs of Stars, Star Clusters, and Nebulæ" was published in December, 1899, by Witherby & Co., 326 High Holborn, London. It contains seventy-two photographs printed in collotype from the original negatives, with descriptive and explanatory letterpress.

nebulous matter. What appeared to be accidental and enigmatical vacuities are shown to be the consequences of cosmogonical action. The hypothesis of the formation of worlds from nebulæ is thus confirmed, if not demonstrated, by the discovery of this new link to connect celestial species. The spiral nebula in Canes Venatici exhibits in a most unmistakable manner a "fluid haze of light, eddying into worlds, and enables us to see cosmic processes at work."*

This nebula may be instructively compared with the ring nebula in Lyra (Plate XX).

Beyond and above any single photograph of a nebula, the camera proves that nebulæ are much vaster than they appear in the most powerful telescope, and this fact strongly supports the hypothesis of Kant and Laplace as to the origin of the universe. In two particulars, however, that hypothesis has been modified by the advance of physical and mathematical research. It was originally framed long before the relations of heat to its sister forces were understood. It is not now deemed necessary to suppose that the primal temperature of the universe was high; the collision of its particles, as attracted together by gravitation, is a quite sufficient explanation of the heat which a star may exhibit when first condensed. Nor is it necessary to suppose that the original condition of cosmical matter was that of a gas; it may have been that of fine dust, or even an aggregation of meteorites, such as

* *Nature*, March 10, 1898.

those which still rotate around the central ball of Saturn. Professor George H. Darwin says that a meteoric swarm, seen from the distance of the stars, would behave like a mass composed of continuous gas.

The triumphs of light in the astronomical camera but reaffirm the solidarity of nature, testifying once more that any new thread caught from her skein leads the explorer not only through labyrinths which puzzled him of old, but to new heavens otherwise hidden for all time. Nothing within human knowledge is more marvellous than the agency, apparently so simple, concerned in all this. A ray of light, infinitesimal in energy, persists on its way, for years it may be, through the whole radius of the universe, untired, untolled; its undulations, intricate beyond full portrayal, arrive with an unconfused story of the physical consistence and chemical nature of their source, of the atmosphere that waylaid them, of the direction in which, and the rate at which, their parent orb was spinning or flying when the ray set out for the earth.

To men of old who knew only what had befallen themselves and their dwelling-place during a few generations, it was but natural to repeat: "The thing that hath been, it is that which shall be: and that which is done is that which shall be done: and there is no new thing under the sun."* But we of to-day are in a different case. The astronomer joining camera to telescope brings

* Ecclesiastes I, 9.

to proof in unexpected fashion that the first act in the cosmical drama, like the last, conforms to the law of derivation, that the universe exhibits in its totality the same rule of descent with modification which the naturalist observes in the moth, or the botanist in the field of wheat. The latest nebular photographs display a continuous series of gradations from the most attenuated wisps of matter to stellar spheres which bear evidence of having been newly ushered into life. "In a forest," said a great astronomer, Sir William Herschel, "we see around us trees in every stage of their life-history. There are the seedlings just bursting from the acorn, the sturdy oaks in their full vigour, those also that are old and near decay and the prostrate trunks of the dead." Much the same succession in the stages of cosmic life are disclosed by the camera, and Evolution stands forth confirmed as true not only of every branch of the tree of life, but of nature as the sum of all things.

Nearly three hundred years ago George Herbert could say

> "Nothing hath got so far
> But man hath caught and kept it as his prey
> His eyes dismount the highest star.
> He is in little all the sphere.
> Herbs gladly cure our flesh, because that they
> Find their acquaintance there."

At the close of the nineteenth century his insight receives confirmation on every hand. We learn with wonder that the scope of life on land and sea, the architecture of the forest, the

ocean and the plain, with all their myriad tenantry, are what they are because the atoms which built them were present, and in such and such proportions, in the birth-cloud of the world. If a rose has tints of incomparable beauty, they are conferred by elements thence derived, whose kin, aflame in an orb a celestial diameter away, send forth the beam needful to reveal that beauty. Were the sun less rich in variety of fuel than it is, the earth, despite its own diversity of substance, would be vastly less a feast for the eye than that newly spread before us at every dawn.

When we remember how disinterested was the quest which has led to so great and unexpected knowledge, we begin to see that the philosopher is often, and unwittingly, the chiefest prospector and the best. It is doubtful whether any path of discovery whatever, no matter how unrelated to utility it may seem, can be pursued without leading to gain at last. No study would at the first glance appear to be more remote from influence upon human thought and feeling than the portrayal of heavenly bodies too distant for telescopic view. Yet that portrayal has served to enlarge our conceptions of the varied forms which worlds and suns may display; the shimmer of the nebulæ enters the camera to corroborate the story of the rock, the plant and the animal as each tells us how it came to be. Adding to vision the eye of artifice, we are confirmed in the faith that nature is intelligible to her inmost

heart, as naught else than the expression of reason, which, infinite in itself, has implanted in the mind of man an undying desire to understand of the infinite all it may.

UNIFORMITY IN GEOLOGICAL CHANGE

SIR CHARLES LYELL

[Sir Charles Lyell, the greatest of English geologists, in the chapter which follows from the eleventh edition of his "Principles of Geology," gave original and powerful support to the theory of evolution. His methods of inquiry and his arguments had much influence on the mind of Charles Darwin. The work here laid under contribution is published by D. Appleton & Co., New York. The books by Professor Shaler, named on page 139 of this volume, will serve as admirable supplementary reading. Sir Archibald Geikie's "Text-Book of Geology," published by the Macmillan Company, New York, in its latest edition is the best work on the subject in the English language.]

ORIGIN OF THE DOCTRINE OF ALTERNATE PERIODS OF REPOSE AND DISORDER

IT HAS been truly observed, that when we arrange the fossiliferous formations in chronological order, they constitute a broken and defective series of monuments: we pass without any intermediate gradations from systems of strata which are horizontal, to other systems which are highly inclined—from rocks of peculiar mineral composition to others which have a character wholly distinct—from one assemblage of organic remains to another, in which frequently nearly all the species and a large part of the genera, are

different. These violations of continuity are so common as to constitute in most regions the rule rather than the exception, and they have been considered by many geologists as conclusive in favour of sudden revolutions in the inanimate and animate world. We have already seen that according to the speculations of some writers there have been in the past history of the planet alternate periods of tranquillity and convulsion, the former enduring for ages and resembling the state of things now experienced by man; the other brief, transient and paroxysmal, giving rise to new mountains, seas and valleys, annihilating one set of organic beings and ushering in the creation of another.

It will be the object of the present chapter to demonstrate that these theoretical views are not borne out by a fair interpretation of geological monuments. It is true that in the solid framework of the globe we have a chronological chain of natural records, many links of which are wanting: but a careful consideration of all the phenomena leads to the opinion that the series was originally defective—that it has been rendered still more so by time—that a great part of what remains is inaccessible to man, and even of that fraction which is accessible nine-tenths or more are to this day unexplored.

The readiest way, perhaps, of persuading the reader that we may dispense with great and sudden revolutions in the geological order of events is by showing him how a regular and un-

interrupted series of changes in the animate and inanimate world must give rise to such breaks in the sequence, and such unconformability of stratified rocks, as are usually thought to imply convulsions and catastrophes. It is scarcely necessary to state that the order of events thus assumed to occur, for the sake of illustration, should be in harmony with all the conclusions legitimately drawn by geologists from the structure of the earth, and must be equally in accordance with the changes observed by man to be now going on in the living as well as in the inorganic creation. It may be necessary in the present state of science to supply some part of the assumed course of nature hypothetically; but if so, this must be done without any violation of probability, and always consistently with the analogy of what is known both of the past and present economy of our system.

In pursuance, then, of the plan above proposed, I will consider, first, the laws which regulate the denudation of strata and the deposition of sediment; secondly, those which govern the fluctuation in the animate world; and, thirdly, the mode in which subterranean movements affect the earth's crust.

UNIFORMITY OF CHANGE CONSIDERED, FIRST, IN REFERENCE TO DENUDATION AND SEDIMENTARY DEPOSITION

First, in regard to the laws governing the deposition of new strata. If we survey the sur-

face of the globe, we immediately perceive that it is divisible into areas of deposition and non-deposition; or, in other words, at any given time there are spaces which are the recipients, others which are not the recipients, of sedimentary matter. No new strata, for example, are thrown down on dry land, which remains the same from year to year; whereas, in many parts of the bottom of seas and lakes, mud, sand and pebbles are annually spread out by rivers and currents. There are also great masses of limestone growing in some seas, chiefly composed of corals and shells, or, as in the depths of the Atlantic, of chalky mud made up of foraminifera and diatomaceæ.

As to the dry land, so far from being the receptacle of fresh accessions of matter, it is exposed almost everywhere to waste away. Forests may be as dense and lofty as those of Brazil and may swarm with quadrupeds, birds and insects, yet at the end of thousands of years one layer of black mould a few inches thick may be the sole representative of those myriads of trees, leaves, flowers and fruits, those innumerable bones and skeletons of birds, quadrupeds and reptiles, which tenanted the fertile region. Should this land be at length submerged, the waves of the sea way wash away in a few hours the scanty covering of mould, and it may merely impart a darker shade of colour to the next stratum of marl, sand, or other matter newly thrown down. So also at the bottom of the ocean where no sedi-

ment is accumulating, seaweed, zoophytes, fish, and even shells, may multiply for ages and decompose, leaving no vestige of their form or substance behind. Their decay, in water, although more slow, is as certain and eventually as complete as in the open air. Nor can they be perpetuated for indefinite periods in a fossil state, unless imbedded in some matrix which is impervious to water, or which at least does not allow a free percolation of that fluid, impregnated, as it usually is, with a slight quantity of carbonic or other acid. Such a free percolation may be prevented either by the mineral nature of the matrix itself, or by the superposition of an impermeable stratum; but if unimpeded, the fossil shell or bone will be dissolved and removed, particle after particle, and thus entirely effaced, unless petrifaction or the substitution of some mineral for the organic matter happens to take place.

That there has been land as well as sea at all former geological periods, we know from the fact that fossils trees and terrestrial plants are imbedded in rocks of every age, except those which are so ancient as to be very imperfectly known to us. Occasionally lake and river shells, or the bones of amphibious or land reptiles, point to the same conclusion. The existence of dry land at all periods of the past implies, as before mentioned, the partial deposition of sediment, or its limitation to certain areas; and the next point to which I shall call the reader's attention is the

shifting of these areas from one region to another.

First, then, variations in the site of sedimentary deposition are brought about independently of subterranean movements. There is always a slight change from year to year, or from century to century. The sediment of the Rhone, for example, thrown into the Lake of Geneva, is now conveyed to a spot a mile and a half distant from that where it accumulated in the tenth century, and six miles from the point where the delta began originally to form. We may look forward to the period when this lake will be filled up, and then the distribution of the transported matter will be suddenly altered, for the mud and sand brought down from the Alps will thenceforth, instead of being deposited near Geneva, be carried nearly two hundred miles southwards, where the Rhone enters the Mediterranean.

In the deltas of large rivers, such as those of the Ganges and Indus, the mud is first carried down for many centuries through one arm, and on this being stopped up it is discharged by another, and may then enter the sea at a point fifty or one hundred miles distant from its first receptacle. The direction of marine currents is also liable to be changed by various accidents, as by the heaping up of new sandbanks, or the wearing away of cliffs and promontories.

But, secondly, all these causes of fluctuation in the sedimentary areas are entirely subordinate to those great upward or downward movements

of land, which will presently be spoken of, as prevailing over large tracts of the globe. By such elevation or subsidence certain spaces are gradually submerged, or made gradually to emerge: in the one case sedimentary deposition may be suddenly renewed after having been suspended for one or more geological periods, in the other as suddenly made to cease after having continued for ages.

If the deposition be renewed after a long interval, the new strata will usually differ greatly from the sedimentary rocks previously formed in the same place, and especially if the older rocks have suffered derangement, which implies a change in the physical geography of the district since the previous conveyance of sediment to the same spot. It may happen, however, that, even where the two groups, the superior and the inferior, are horizontal and conformable to each other, they may still differ entirely in mineral character, because, since the origin of the older formation, the geography of some distant country has been altered. In that country rocks before concealed may have become exposed by denudation; volcanoes may have burst out and covered the surface with scoriæ and lava; or new lakes, intercepting the sediment previously conveyed from the upper country, may have been formed by subsidence; and other fluctuations may have occurred, by which the materials brought down from thence by rivers to the sea have acquired a distinct mineral character.

It is well known that the stream of the Mississippi is charged with sediment of a different colour from that of the Arkansas and Red Rivers, which are tinged with red mud, derived from rocks of porphyry and red gypseous clays in "the far west." The waters of the Uruguay, says Darwin, draining a granitic country, are clear and black, those of the Parana, red. The mud with which the Indus is loaded, says Burnes, is of a clayey hue, that of the Chenab, on the other hand, is reddish, that of the Sutlej is more pale. The same causes which make these several rivers, sometimes situated at no great distance the one from the other, to differ greatly in the character of their sediment, will make the waters draining the same country at different epochs, especially before and after great revolutions in physical geography, to be entirely dissimilar. It is scarcely necessary to add that marine currents will be affected in an analogous manner in consequence of the formation of new shoals, the emergence of new islands, the subsidence of others, the gradual waste of neighbouring coasts, the growth of new deltas, the increase of coral reefs, volcanic eruptions, and other changes.

UNIFORMITY OF CHANGE CONSIDERED, SECONDLY, IN REFERENCE TO THE LIVING CREATION

Secondly, in regard to the vicissitudes of the living creation, all are agreed that the successive groups of sedimentary strata found in the earth's crust are not only dissimilar in mineral composi-

tion for reasons above alluded to, but are likewise distinguishable from each other by their organic remains. The general inference drawn from the study and comparison of the various groups, arranged in chronological order, is this: that at successive periods distinct tribes of animals and plants have inhabited the land and waters, and that the organic types of the newer formations are more analogous to species now existing than those of more ancient rocks. If we then turn to the present state of the animate creation, and enquire whether it has now become fixed and stationary, we discover that, on the contrary, it is in a state of continual flux—that there are many causes in action which tend to the extinction of species, and which are conclusive against the doctrine of their unlimited durability.

There are also causes which give rise to new varieties and races in plants and animals, and new forms are continually supplanting others which had endured for ages. But natural history has been successfully cultivated for so short a period, that a few examples only of local, and perhaps but one or two of absolute, extirpation of species can as yet be proved, and these only where the interference of man has been conspicuous. It is evident that man is not the only exterminating agent; and that, independently of his intervention, the annihilation of species is promoted by the multiplication and gradual diffusion of every animal or plant. It will also appear that every alteration in the physical

geography and climate of the globe cannot fail to have the same tendency. If we proceed still farther, and enquire whether new species are substituted from time to time for those which die out, we find that the successive introduction of new forms appears to have been a constant part of the economy of the terrestrial system, and if we have no direct proof of the fact it is because the changes take place so slowly as not to come within the period of exact scientific observation. To enable the reader to appreciate the gradual manner in which a passage may have taken place from an extinct fauna to that now living, I shall say a few words on the fossils of successive Tertiary periods. When we trace the series of formations from the more ancient to the more modern, it is in these Tertiary deposits that we first meet with assemblages of organic remains having a near analogy to the fauna of certain parts of the globe in our own time. In the Eocene, or oldest subdivisions some few of the testacea [animals having hard shells] belong to existing species, although almost all of them, and apparently all the associated vertebrata, are now extinct. These Eocene strata are succeeded by a great number of more modern deposits, which depart gradually in the character of their fossils from the Eocene type, and approach more and more to that of the living creation. In the present state of science, it is chiefly by the aid of shells that we are enabled to arrive at these results, for of all classes the tes-

tacea are the most generally diffused in a fossil state, and may be called the medals principally employed by nature in recording the chronology of past events. In the Upper Miocene rocks we begin to find a considerable number, although still a minority, of recent species, intermixed with some fossils common to the preceding, or Eocene, epoch. We then arrive at the Pliocene strata, in which species now contemporary with man begin to preponderate, and in the newest of which nine-tenths of the fossils agree with species still inhabiting the neighbouring sea. It is in the Post-Tertiary strata, where all the shells agree with species now living, that we have discovered the first or earliest known remains of man associated with the bones of quadrupeds, some of which are of extinct species.

In thus passing from the older to the newer members of the Tertiary system, we meet with many chasms, but none which separate entirely, by a broad line of demarkation, one state of the organic world from another. There are no signs of an abrupt termination of one fauna and flora, and the starting into life of new and wholly distinct forms. Although we are far from being able to demonstrate geologically an insensible transition from the Eocene to the Miocene, or even from the latter to the recent fauna, yet the more we enlarge and perfect our general survey, the more nearly do we approximate to such a continuous series, and the more gradually are we conducted from times when

many of the genera and nearly all the species were extinct, to those in which scarcely a single species flourished, which we do not know to exist at present. Dr. A. Philippi, indeed, after an elaborate comparison of the fossil tertiary shells of Sicily with those now living in the Mediterranean, announced, as the result of his examination, that there are strata in that island which attest a very gradual passage from a period when only thirteen in a hundred of the shells were like the species now living in the sea, to an era when the recent species had attained a proportion of ninety-five in a hundred. There is, therefore, evidence, he says, in Sicily of this revolution in the animate world having been effected "without the intervention of any convulsion or abrupt changes, certain species having from time to time died out, and others having been introduced, until at length the existing fauna was elaborated."

In no part of Europe is the absence of all signs of man or his works, in strata of comparatively modern date, more striking than in Sicily. In the central parts of that island we observe a lofty table-land and hills, sometimes rising to the height of 3,000 feet, capped with a limestone, in which from 70 to 85 per cent. of the fossil testacea are specifically identical with those now inhabiting the Mediterranean. These calcareous [chalky or lime bearing] and other argillaceous [clayey] strata of the same age are intersected by deep valleys which appear to have been gradually

formed by denudation, but have not varied materially in width or depth since Sicily was first colonized by the Greeks. The limestone, moreover, which is of so late a date in geological chronology, was quarried for building those ancient temples of Girgenti and Syracuse, of which the ruins carry us back to a remote era in human history. If we are lost in conjectures when speculating on the ages required to lift up these formations to the height of several thousand feet above the sea, and to excavate the valleys, how much more remote must be the era when the same rocks were gradually formed beneath the waters!

The intense cold of the Glacial period profoundly affected terrestrial life. Although we have not yet succeeded in detecting proofs of the origin of man antecedently to that epoch, we have yet found evidence that most of the testacea, and not a few of the quadrupeds, which preceded, were of the same species as those which followed the extreme cold. To whatever local disturbances this cold may have given rise in the distribution of species, it seems to have done little in effecting their annihilation. We may conclude therefore, from a survey of the tertiary and modern strata, which constitute a more complete and unbroken series than rocks of older date, that the extinction and creation of species have been and are, the result of a slow and gradual change in the organic world.

UNIFORMITY OF CHANGE CONSIDERED, THIRDLY IN REFERENCE TO SUBTERRANEAN MOVEMENTS

Thirdly, to pass on to the last of the three topics before proposed for discussion, the earthquakes recorded in history, certain countries have, from time immemorial, been rudely shaken again and again; while others, comprising by far the larger part of the globe, have remained to all appearance motionless. In the regions of convulsion rocks have been rent asunder, the surface has been forced up into ridges, chasms have been opened, or the ground throughout large spaces has been permanently lifted up above or let down below its former level. In the regions of tranquillity some areas have remained at rest, but others have been ascertained, by a comparison of measurements made at different periods, to have risen by an insensible motion, as in Sweden, or to have subsided very slowly, as in Greenland. That these same movements, whether ascending or descending, have continued for ages in the same direction has been established by historical or geological evidence. Thus we find on the opposite coasts of Sweden that brackish water deposits, like those now forming in the Baltic, occur on the eastern side, and upraised strata filled with purely marine shells, now proper to the ocean, on the western coast. Both of these have been lifted up to an elevation of several hundred feet above high-water mark. The rise

within the historical period has not amounted to many yards, but the greater extent of antecedent upheaval is proved by the occurrence in inland spots, several hundred feet high, of deposits filled with fossil shells of species now living either in the ocean or the Baltic.

It must in general be more difficult to detect proofs of slow and gradual subsidence than of elevation, but the theory which accounts for the form of circular coral reefs and lagoon islands, and which will be explained in the concluding chapter of this work, will satisfy the reader that there are spaces on the globe, several thousand miles in circumference, throughout which the downward movement has predominated for ages, and yet the land has never, in a single instance, gone down suddenly for several hundred feet at once. Yet geology demonstrates that the persistency of subterranean movements in one direction has not been perpetual throughout all past time. There have been great oscillations of level, by which a surface of dry land has been submerged to a depth of several thousand feet, and then at a period long subsequent raised again and made to emerge. Nor have the regions now motionless been always at rest; and some of those which are at present the theatres of reiterated earthquakes have formerly enjoyed a long continuance of tranquillity. But, although disturbances have ceased after having long prevailed, or have recommenced after a suspension for ages, there has been no universal disruption

of the earth's crust or desolation of the surface since times the most remote. The non-occurrence of such a general convulsion is proved by the perfect horizontality now retained by some of the most ancient fossiliferous [fossil bearing] strata throughout wide areas.

That the subterranean forces have visited different parts of the globe at successive periods is inferred chiefly from the unconformability of strata belonging to groups of different ages. Thus, for example, on the borders of Wales and Shropshire, we find the slaty beds of the ancient Silurian system inclined and vertical, while the beds of the overlying carboniferous shale and sandstone are horizontal. All are agreed that in such a case the older set of strata had suffered great disturbance before the deposition of the newer or carboniferous beds, and that these last have never since been violently fractured, nor have ever been bent into folds, whether by sudden or continuous lateral pressure. On the other hand, the more ancient or Silurian group suffered only a local derangement, and neither in Wales nor elsewhere are all the rocks of that age found to be curved or vertical.

In various parts of Europe, for example, and particularly near Lake Wener in the south of Sweden, and in many parts of Russia, the Silurian strata maintain the most perfect horizontality; and a similar observation may be made respecting limestones and shales of like antiquity in the great lake district of Canada and the United

States. These older rocks are still as flat and horizontal as when first formed; yet, since their origin, not only have most of the actual mountain-chains been uplifted, but some of the very rocks of which those mountains are composed have been formed, some of them by igneous and others by aqueous action.

It would be easy to multiply instances of similar unconformability in formations of other ages; but a few more will suffice. The carboniferous rocks before alluded to as horizontal on the borders of Wales are vertical in the Mendip hills, Somersetshire, where the overlying beds of the New Red Sandstone are horizontal. Again, in the Wolds of Yorkshire the last-mentioned sandstone supports on its curved and inclined beds the horizontal Chalk. The Chalk again is vertical on the flanks of the Pyrenees, and the tertiary strata repose uncomformably upon it.

As almost every country supplies illustrations of the same phenomena, they who advocate the doctrine of alternate periods of disorder and repose may appeal to the facts above described, as proving that every district has been by turns convulsed by earthquakes and then respited for ages from convulsions. But so it might with equal truth be affirmed that every part of Europe has been visited alternately by winter and summer, although it has always been winter and always summer in some part of the planet, and neither of these seasons has ever reigned simultaneously over the entire globe. They have

been always shifting from place to place; but the vicissitudes which recur thus annually in a single spot are never allowed to interfere with the invariable uniformity of seasons throughout the whole planet.

So, in regard to subterranean movements, the theory of the perpetual uniformity of the force which they exert on the earth's crust is quite consistent with the admission of their alternate development and suspension for long and indefinite periods within limited geographical areas.

If, for reasons before stated, we assume a continual extinction of species and appearance of others on the globe, it will then follow that the fossils of strata formed at two distant periods on the same spot will differ even more certainly than the mineral composition of those strata. For rocks of the same kind have sometimes been reproduced in the same district after a long interval of time; whereas all the evidence derived from fossil remains is in favour of the opinion that species that have once died out have never been reproduced. The submergence, then, of land must be often attended by the commencement of a new class of sedimentary deposits, characterized by a new set of fossil animals and plants, while the reconversion of the bed of the sea into land may arrest at once and for an indefinite time the formation of geological monuments. Should the land again sink, strata will again be formed; but one or many entire revolu-

tions in animal or vegetable life may have been completed in the interval.

As to the want of completeness in the fossiliferous series, which may be said to be almost universal, we have only to reflect on what has been already said of the laws governing sedimentary deposition, and those which give rise to fluctuations in the animate world, to be convinced that a very rare combination of circumstances can alone give rise to such a superposition and preservation of strata as will bear testimony to the gradual passage from one state of organic life to another. To produce such strata nothing less will be requisite than the fortunate coincidence of the following conditions: first, a never-failing supply of sediment in the same region throughout a period of vast duration; secondly, the fitness of the deposit in every part for the permanent preservation of embedded fossils; and, thirdly, a gradual subsidence to prevent the sea or lake from being filled up and converted into land.

In certain parts of the Pacific and Indian Oceans, most of these conditions, if not all, are complied with, and the constant growth of coral, keeping pace with the sinking of the bottom of the sea, seems to have gone on so slowly, for such indefinite periods, that the signs of a gradual change in organic life might probably be detected in that quarter of the globe if we could explore its submarine geology. Instead of the growth of coralline limestone, let us suppose, in some

other place, the continuous deposition of river mud and sand, such as the Ganges and Brahmapootra have poured for thousands of years into the Bay of Bengal. Part of this bay, although of considerable depth, might at length be filled up before an appreciable amount of change was effected in the fish, mollusca, and other inhabitants of the sea and neighbouring land. But if the bottom be lowered by sinking at the same rate that it is raised by river mud, the bay can never be turned into dry land. In that case one new layer of matter may be superimposed upon another for a thickess of many thousand feet, and the fossils of the inferior beds may differ greatly from those entombed in the uppermost, yet every intermediate gradation may be indicated in the passage from an older to a newer assemblage of species. Granting, however, that such an unbroken sequence of monuments may thus be elaborated in certain parts of the sea, and that the strata happen to be all of them well adapted to preserve the included fossils from decomposition, how many accidents must still concur before these submarine formations will be laid open to our investigation! The whole deposit must first be raised several thousand feet in order to bring into view the very foundation; and during the process of exposure the superior beds must not be entirely swept away by denudation.

In the first place, the chances are nearly as three to one against the mere emergence of the

mass above the waters, because nearly three-fourths of the globe are covered by the ocean. But if it be upheaved and made to constitute part of the dry land, it must also, before it can be available for our instruction, become part of that area already surveyed by geologists. In this small fraction of land already explored, and still very imperfectly known, we are required to find a set of strata deposited under peculiar conditions, and which, having been originally of limited extent, would have been probably much lessened by subsequent denudation.

Yet it is precisely because we do not encounter at every step the evidence of such gradations from one state of the organic world to another, that so many geologists have embraced the doctrine of great and sudden revolutions in the history of the animate world. Not content with simply availing themselves, for the convenience of classification, of those gaps and chasms which here and there interrupt the continuity of the chronological series, as at present known, they deduce, from the frequency of these breaks in the chain of records, an irregular mode of succession in the events themselves, both in the organic and inorganic world. But, besides that some links of the chain which once existed are now entirely lost and others concealed from view we have good reason to suspect that it was never complete originally. It may undoubtedly be said that strata have been always forming somewhere, and therefore at every moment of past

time Nature has added a page to her archives; but, in reference to this subject, it should be remembered that we can never hope to compile a consecutive history by gathering together monuments which were originally detached and scattered over the globe. For, as the species of organic beings contemporaneously inhabiting remote regions are distinct, the fossils of the first several periods which may be preserved in any one country, as in America for example, will have no connection with those of a second period found in India, and will therefore no more enable us to trace the signs of a gradual change in the living creation, than a fragment of Chinese history will fill up a blank in the political annals of Europe.

The absence of any deposits of importance containing recent shells in Chili, or anywhere on the western coast of South America, naturally led Mr. Darwin to the conclusion that "where the bed of the sea is either stationary or rising, circumstances are far less favourable than where the level is sinking to the accumulation of conchiferous [shell-bearing] strata of sufficient thickness and extension to resist the average vast amount of denudation." In like manner the beds of superficial sand, clay, and gravel, with recent shells, on the coasts of Norway and Sweden, where the land has risen in Post-tertiary times, are so thin and scanty as to incline us to admit a similar proposition. We may in fact assume that in all cases where the bottom of the sea has been undergoing continuous elevation, the total

thickness of sedimentary matter accumulating at depths suited to the habitation of most of the species of shells can never be great, nor can the deposits be thickly covered by superincumbent matter, so as to be consolidated by pressure. When they are upheaved, therefore, the waves on the beach will bear down and disperse the loose materials; whereas, if the bed of the sea subsides slowly, a mass of strata, containing abundance of such species as live at moderate depths, may be formed and may increase in thickness to any amount. It may also extend horizontally over a broad area, as the water gradually encroaches on the subsiding land.

Hence it will follow that great violations of continuity in the chronological series of fossiliferous rocks will always exist, and the imperfection of the record, though lessened, will never be removed by future discoveries. For not only will no deposits originate on the dry land, but those formed in the sea near land, which is undergoing constant upheaval, will usually be too slight in thickness to endure for ages.

In proportion as we become acquainted with larger geographical areas, many of the gaps, by which a chronological table is rendered defective, will be removed. We were enabled by aid of the labours of Prof. Sedgwick and Sir Roderick Murchison, to intercalate, in 1838, the marine strata of the Devonian period, with their fossil shells, corals, and fish, between the Silurian and Carboniferous rocks. Previously the marine

fauna of these last-mentioned formations wanted the connecting links which now render the passage from the one to the other much less abrupt. In like manner the Upper Miocene has no representative in England, but in France, Germany, and Switzerland it constitutes a most instructive link between the living creation and the middle of the great Tertiary period. Still we must expect, for reasons before stated, that chasms will forever continue to occur, in some parts of our sedimentary series.

CONCLUDING REMARKS ON THE CONSISTENCY OF THE THEORY OF GRADUAL CHANGE WITH THE EXISTENCE OF GREAT BREAKS IN THE SERIES

To return to the general argument pursued in this chapter, it is assumed, for reasons above explained, that a slow change of species is in simultaneous operation everywhere throughout the habitable surface of sea and land; whereas the fossilization of plants and animals is confined to those areas where new strata are produced. These areas, as we have seen, are always shifting their position, so that the fossilizing process, by means of which the commemoration of the particular state of the organic world, at any given time, is effected, may be said to move about, visiting and revisiting different tracts in succession.

To make still more clear the supposed working

of this machinery, I shall compare it to a somewhat analogous case that might be imagined to occur in the history of human affairs. Let the mortality of the population of a large country represent the successive extinction of species, and the births of new individuals the introduction of new species. While these fluctuations are gradually taking place everywhere, suppose commissioners to be appointed to visit each province of the country in succession, taking an exact account of the number, names, and individual peculiarities of all the inhabitants, and leaving in each district a register containing a record of this information. If, after the completion of one census, another is immediately made on the same plan, and then another, there will at last be a series of statistical documents in each province. When those belonging to any one province are arranged in chronological order, the contents of such as stand next to each other will differ according to the length of the intervals of time between the taking of each census. If, for example, there are sixty provinces, and all the registers are made in a single year and renewed annually, the number of births and deaths will be so small, in proportion to the whole of the inhabitants, during the interval between the compiling of two consecutive documents, that the individuals described in such documents will be nearly identical; whereas, if the survey of each of the sixty provinces occupies all the commissioners for a whole year, so that they are unable

to revisit the same place until the expiration of sixty years, there will then be an almost entire discordance between the persons enumerated in two consecutive registers in the same province. There are, undoubtedly, other causes, besides the mere quantity of time, which may augment or diminish the amount of discrepancy. Thus, at some periods a pestilential disease may have lessened the average duration of human life; or a variety of circumstances may have caused the births to be unusually numerous, and the population to multiply; or a province may be suddenly colonized by persons migrating from surrounding districts.

These exceptions may be compared to the accelerated rate of fluctuations in the fauna and flora of a particular region, in which the climate and physical geography may be undergoing an extraordinary degree of alteration.

But I must remind the reader that the case above proposed has no pretensions to be regarded as an exact parallel to the geological phenomena which I desire to illustrate; for the commissioners are supposed to visit the different provinces in rotation; whereas the commemorating processes by which organic remains become fossilized, although they are always shifting from one area to the other, are yet very irregular in their movements. They may abandon and revisit many spaces again and again, before they once approach another district; and, besides this source of irregularity, it may often

happen that, while the depositing process is suspended, denudation may take place, which may be compared to the occasional destruction by fire or other causes of some of the statistical documents before mentioned. It is evident that where such accidents occur the want of continuity in the series may become indefinitely great, and that the monuments which follow next in succession will by no means be equidistant from each other in point of time.

If this train of reasoning be admitted, the occasional distinctness of the fossil remains, in formations immediately in contact, would be a necessary consequence of the existing laws of sedimentary deposition and subterranean movement, accompanied by a constant dying out and renovation of species.

As all the conclusions above insisted on are directly opposed to opinions still popular, I shall add another comparison, in the hope of preventing any possible misapprehension of the argument. Suppose we had discoverd two buried cities at the foot of Vesuvius, immediately superimposed upon each other, with a great mass of tuff and lava intervening, just as Portici and Resina, if now covered with ashes, would overlie Herculaneum. An antiquary might possibly be entitled to infer, from the inscriptions on public edifices, that the inhabitants of the inferior and older city were Greeks, and those of the modern towns Italians. But he would reason very hastily if he also concluded from these data, that

there had been a sudden change from the Greek to the Italian language in Campania. But if he afterwards found *three* buried cities, one above the other, the intermediate one being Roman, while, as in the former example, the lowest was Greek and the uppermost Italian, he would then perceive the fallacy of his former opinion, and would begin to suspect that the catastrophes, by which the cities were inhumed, might have no relation whatever to the fluctuations in the language of the inhabitants; and that, as the Roman tongue had evidently intervened between the Greek and Italian, so many other dialects may have been spoken in succession, and the passage from the Greek to the Italian may have been very gradual, some terms growing obsolete, while others were introduced from time to time.

If this antiquary could have shown that the volcanic paroxysms of Vesuvius were so governed as that cities should be buried one above the other, just as often as any variation occurred in the language of the inhabitants, then, indeed, the abrupt passage from a Greek to a Roman, and from a Roman to an Italian city, would afford proof of fluctuations no less sudden in the language of the people.

So, in Geology, if we could assume that it is part of the plan of Nature to preserve, in every region of the globe, an unbroken series of monuments to commemorate the vicissitudes of the organic creation, we might infer the sudden extirpation of species, and the simultaneous intro-

duction of others, as often as two formations in contact are found to include dissimilar organic fossils. But we must shut our eyes to the whole economy of the existing causes, aqueous, igneous, and organic, if we fail to perceive *that such is not the plan of Nature.*

I shall now conclude the discussion of the question whether there has been any interruption from the remotest periods, of one uniform and continuous system of change in the animate and inanimate world. We were induced to enter into that enquiry by reflecting how much the progress of opinion in Geology had been influenced by the assumption that the analogy was slight in kind, and still more slight in degree, between the causes which produced the former revolutions of the globe, and those now in everyday operation. It appeared clear that the earlier geologists had not only a scanty aquaintance with existing changes, but were singularly unconscious of the amount of their ignorance. With the presumption naturally inspired by this unconsciousness, they had no hesitation in deciding at once that time could never enable the existing powers of nature to work out changes of great magnitude, still less such important revolutions as those which are brought to light by Geology. They therefore felt themselves at liberty to indulge their imaginations in guessing at what *might be*, rather than enquiring *what is;* in other words, they employed themselves in conjecturing what might have been the course of Nature in their own times.

It appeared to them far more philosophical to speculate on the possibilities of the past, than patiently to explore the realities of the present; and having invented theories under the influence of such maxims, they were consistently unwilling to test their validity by the criterion of their accordance with the ordinary operations of Nature. On the contrary, the claims of each new hypothesis to credibility appeared enhanced by the great contrast, in kind or intensity, of the causes referred to and those now in operation.

Never was there a dogma more calculated to foster indolence, and to blunt the keen edge of curiosity, than this assumption of the discordance between the ancient and existing causes of change. It produced a state of mind unfavourable in the highest degree to the candid reception of the evidence of those minute but incessant alterations which every part of the earth's surface is undergoing, and by which the condition of its inhabitants is continually made to vary. The student, instead of being encouraged with the hope of interpreting the enigmas presented to him in the earth's structure—instead of being prompted to undertake laborious enquiries into the natural history of the organic world, and the complicated effects of the igneous and aqueous causes now in operation—was taught to despond from the first. Geology, it was affirmed, could never rise to the rank of an exact science; the greater number of phenomena must for ever remain inexplicable, or only be partially eluci-

dated by ingenious conjectures. Even the mystery which invested the subject was said to constitute one of its principal charms, affording, as it did, full scope to the fancy to indulge in a boundless field of speculation.

The course directly opposed to this method of philosophizing consists in an earnest and patient enquiry, how far geological appearances are reconcilable with the effect of changes now in progress, or which may be in progress in regions inaccessible to us, but of which the reality is attested by volcanoes and subterranean movements. It also endeavours to estimate the aggregate result of ordinary operations multiplied by time, and cherishes a sanguine hope that the resources to be derived from observation and experiment, or from the study of Nature such as she now is, are very far from being exhausted. For this reason all theories are rejected which involve the assumption of sudden and violent catastrophes and revolutions of the whole earth, and its inhabitants—theories which are restrained by no reference to existing analogies, and in which a desire is manifested to cut, rather than patiently to untie, the Gordian knot.

We have now, at least, the advantage of knowing, from experience, that an opposite method has always put geologists on the road that leads to truth.—suggesting views which, although imperfect at first, have been found capable of improvement, until at last adopted

by universal consent; while the method of speculating on a former distinct state of things and causes has led invariably to a multitude of contradictory systems, which have been overthrown one after the other—have been found incapable of modification—and which have often required to be precisely reversed.

The remainder of this work will be devoted to an investigation of the changes now going on in the crust of the earth and its inhabitants. The importance which the student will attach to such researches will mainly depend on the degree of confidence which he feels in the principles above expounded. If he firmly believes in the resemblance or identity of the ancient and present system of terrestrial changes, he will regard every fact collected respecting the causes in diurnal action as affording him a key to the interpretation of some mystery in the past. Events which have occurred at the most distant periods in the animate and inanimate world will be acknowledged to throw light on each other, and the deficiency of our information respecting some of the most obscure parts of the present creation will be removed. For as, by studying the external configuration of the existing land and its inhabitants, we may restore in imagination the appearance of the ancient continents which have passed away, so may we obtain from the deposits of ancient seas and lakes an insight into the nature of the subaqueous processes now in operation, and of many forms of organic life which,

though now existing, are veiled from sight. Rocks, also, produced by subterranean fire in former ages, at great depths in the bowels of the earth, present us, when upraised by gradual movements, and exposed to the light of heaven, with an image of those changes which the deep-seated volcano may now occasion in the nether regions. Thus, although we are mere sojourners on the surface of the planet, chained to a mere point in space, enduring but for a moment of time, the human mind is not only enabled to number worlds beyond the unassisted ken of mortal eye, but to trace the events of indefinite ages before the creation of our race, and is not even withheld from penetrating into the dark secrets of the ocean, or the interior of the solid globe; free, like the spirit which Virgil described as animating the universe:—

> ———ire per omnes
> Terrasque, tractusque maris, cœlumque profundum.

[——moving through all lands, and spaces of the sea and the depth of heaven.]

RIVERS AND VALLEYS

PROFESSOR NATHANIEL SOUTHGATE SHALER

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THE greater part of the facts with which geologists have to deal possess for the general public a recondite character. They concern things which are not within the limits of familiar experience. In treating of them, the science uses a language of its own, an *argot* as special as that of the anatomist or the metaphysician. There is, however, one branch of the subject the matter of which demands no special knowledge for its understanding, viz.: the surface of the earth. At first, geologists were little inclined to deal with the part of their field which is visited by the sun. Gradually, however, they have come to see that this outer face of the earth is not only a kindlier but a more legible part of the great stone book, and they have made a division of their work which they entitle Surface Geology. In this division they include all that is evident to the

untrained understanding, the contour of land and of sea-floor, the aspect of shores, the conditions of soil, etc. Under the head of Rivers and Valleys we propose to consider one portion of this simple but ample division of geologic science.

If the reader wishes to begin a series of studies of an unprofessional character which will lead him to some of the most important fields of knowledge which the earth's science can open to him, he cannot do better than find his way to his subject through a river-valley. There are many advantages offered to him in beginning his inquiries in this pleasant way. In the first place, the outward aspect of the phenomena with which he has to deal is already familiar to him. We can all recall to mind some of these troughs of the earth through which flows a stream, be it mountain-torrent, brook, or river. The steep or gentle slopes of the valley toward the agent which has constructed it, the flowing water, as well as many of the important actions of the stream in its times of flood or in its cataracts, are also familiar. In fact, there is not a feature or a phenomenon visible in the valley which has not a proper name, indicating that it is a matter of common and easy observation. Whoever will follow an ordinary stream from its source to the sea in such a journey as he may make in a few days' travelling, and will avail himself of its teachings, with the aid of the simplest understandings derived from a knowledge of physical

laws, will obtain a clew to a very large part of the earth's machinery.

To see the actual beginning of the river under the conditions which are best for our inquiry, we must observe the surface at some point on the dividing line between two streams where they head together, near the crest of a mountain, in a time of rain. All that is visible are the drops of rain which slip out of the air and patter on the surface of the earth. We must be prepared at the outset to look past this simple fact of rainfall and to conceive the physical history of the drop of water since it left the surface of the earth in its journey through the clouds and back to earth again.

The story of the rain-drop before it comes to the earth is very simple. The heat from the sun, aided in a small measure by the heat from all the stars, evaporates the water from the earth's surface, mainly from the sea, and removes it in the state of vapor to a height of many thousand feet above the earth's surface. It is maintained there by the heat which it has absorbed, and thus the main spring of the rain is in the sun. After abiding awhile in the upper regions of the atmosphere, by some of the many chances which beset the clouds, the vapor is cooled; it condenses from the loss of heat, and falls as rain or snow. The circumstances of our imaginary mountain top, if that summit be at a considerable height above the sea, favour the cooling of the cloud and therefore the precipitation of

this rain. These uplands retain the cold of winter, and during night they pour forth their heat by radiation through the thin air, with more rapidity than the lower lands, which are covered beneath a thicker blanket of atmosphere.

When the drop of rain falls to the earth's surface, if it be of ordinary size, it gives a sensible blow. If that surface be covered with a thin layer of scattered sand-grains or small pebbles, we may observe that the bits of rock dance about and thus apply a little of the force which comes from the drop, to rub the stone on which they lie. At first, the water spreads over the earth's surface as a thin sheet, but as that surface is never perfectly level, it is, provided the rock be bare, quickly gathered into rivulets; or if it be covered with mosses, or the thin layer of porous soil common to mountain-tops, it may for a moment disappear from sight in the spongy mass; but a little farther down, we find that it is gathered in rivulets, which quickly join together, so that in descending even a hundred feet below the summit, in a time of rain, we find a number of shallow valleys, each occupied by a little rivulet. The union of these streams gives us one of more power, which may be taken as a typical mountain torrent. We observe that such a stream descends with considerable rapidity; it is rare indeed that it does not have a fall of more than fifty feet to a mile. The rate of fall in steep-faced mountains often amounts to as much as five hundred feet in that distance.

As soon as the stream is more than two or three feet wide and a foot in depth, we begin to see evidences of its energy. Even if the fall be but at the rate of fifty feet to the mile, we shall find that such a stream is able to urge forward with great violence masses of stone several inches in diameter. If we roll a stone the size of a man's head into the channel, it is swept along, bumping violently against the obstacles it encounters, striking first one rock-bank and then another, until it becomes fixed in some crevice. If, after the pebble has journeyed for a few hundred feet, we recover it from the stream, it is often easy to note the dents on its surface, produced by the collisions on its journey. In most cases there has been a corresponding blow and an equal wearing inflicted on the firm rocks against which it collided.

A little observation with streams having different rates of fall will show the observer that the ease with which a stone is urged onward, and the size of those which a stream of given volume can carry, depend in a remarkable way on the rate of its descent toward the sea level, and therefore on the velocity with which its waters flow. Computation and experience have shown that this increase in speed is proportionate at least to the cube, or third power, of the velocity with which the current flows. One distinguished student of this hydraulic problem has come to the conclusion that the increase of the propulsive power of the stream upon the fragments which

it encounters is as the sixth power of its speed. It is not worth while for us to pause in our imaginary journey to consider whether the third power or the sixth be the rate at which the efficiency in the carrying power of the stream increases with its speedier flow. It is enough for us to know that the water, with very slight increase in its velocity, is able to carry a very much larger stone than it could before its speed was increased.

The sides of these mountain torrents are generally steep. It is rare indeed that the slopes which lead to them are much less inclined than the roofs of ordinary houses. Over all the surface on either side of the torrent, frost and other agents of decay are constantly at work breaking out bits of stone or forming soil. This mass of broken-up rock is constantly slipping down the sides of the valley. Every time the winter frost seizes it, it expands a little, and is thus shoved downward; frequently, when soaked with water, great sheets of it slip swiftly, as mud-avalanches, into the stream. In this way the torrent is always provided with fragments which it may grind up into pebbles, sand, and mud, and bear onward to the fields below. In times of drought, these stream-beds are occupied by rivulets of clear water, and at such periods the observer gains no idea of the vigour with which the mill works; but in times of heavy rain he will find the water turbid with sediment made by the attrition of pebbles against the bordering walls of

the stream and upon each other. He then sees whence comes the sediments which are so important a feature in the lower portions of the river-system. From any commanding elevation in a mountain district, we may see scores or hundreds of those torrent-beds within one field of view. In periods of heavy rain, the roar arising from the moving stones is often a very striking feature.

Descending the channel of any of these mountain torrents, we find that after a few miles of course, though the brook steadily gains in volume by the contributions of tributary streams, it gradually diminishes the swiftness of its descent. At a certain point it ceases to bear onward all of the larger stones which come into its possession. There fragments gather upon the banks, forming a rude terrace. Still farther down, where the slope is less considerable, the smaller pebbles are left behind, crowded into the interstices of the larger fragments. The terrace becomes more distinct, vegetation gathers upon it, and the waste of the plants forms a soil which partially levels off the surface. Farther on, we come to the field where the annual overflow of the stream during the spring floods heaps a quantity of the sand and mud upon this foundation of coarser material; we then have the beginning of the alluvial terrace. At first this alluvial terrace is but a narrow belt on either side of the stream which, swollen by its flood-waters, often breaks new channels through this

bench of detrital matter. In fact, all this marginal accumulation is of temporary duration, for the stream is as yet wild, and in its annual floods is apt to undo the construction-work of the previous years.

When the stream comes to have a distinct and somewhat enduring alluvial belt on either side of its path, it has entered on the stage of a river. It is indeed on the presence of this marginal accumulation that we most rest the distinction between a torrent and a river. From the place where the terraces begin to form, downward to the mouth of the stream, the conditions of its flow are vastly affected by its reactions upon this detrital matter. In most cases, with each mile of its descent the magnitude of these deposits increases. The alluvial lands stretch farther and farther on either side; the materials which compose them grow finer as we descend in the valley, for the reason that with this descent the slope of the stream in most cases steadfastly diminishes and its ability to urge forward coarse sediments decreases in a rapid ratio.

The alluvial deposits which border our rivers owe their existence to the fact that the torrential head-waters, by their great velocity, bear forward, beyond the mountain districts, a large amount of materials which are of such a coarse nature that the larger but less powerful lower part of the stream cannot urge them onward to the sea. In all its journey to the ocean, the

river is continually struggling with this detritus. It deals with this burden in the following manner: The motion of the stream is swiftest in its central parts, because, in most cases, the water is deepest in that part of its bed, and is therefore the least influenced by friction. On the sides of the stream where the water is shoal, the current is least swift; therefore in these marginal parts it constantly tends to lay down sediments. As soon as the alluvial terrace is formed, certain kinds of trees, particularly our willows and aspens, find a lodgment upon it. They push their roots out into the nutritious mud and enmesh it in their net-work of fibres; they also send up from these roots a thick hedge of stems, in which the flood-waters lose their swiftness of motion and therefore drop their contained sediments. In the state of nature, all our American streams, and those of most other countries as well, are bordered by a close array of these plants, all of which are at work to win against the channel of the stream. But for the cutting power of the stream, they would quickly close its channel; as it is, they constantly crowd its waters within a narrow pathway.

Against the encroachments of the alluvial banks brought about by the action of the water-loving trees, the river prevails by fits and starts, under the action of a curious law which causes its current to rebound from bank to bank. The nature of this principle of rebounding can best be seen by observing the effect arising where a jetty is built at

any point in the course of one of our larger rivers. The jetty causes the water to sweep away from its obstruction and to strike against the opposite shore. The crowding against the shore gives its current increased power; it will wrest away the alluvium from the grasp of the roots, and will then cut under the trees, causing considerable areas of forests to be precipitated into the waters and borne away to the sea. From the point of impact, the current will again rebound in a manner which will cause it, at a certain distance below, to strike against the opposite bank, where it will again make swift encroachment against the forest protection. After this second assault, it will swing across to a lower point on the shore against which it first impinged, and so the oscillations from side to side will be propagated down stream it may be for a hundred miles or more. A single jetty of this description, as it has been observed in the rivers of India, will affect the oscillations of the current for an indefinite distance downward in its course. That which is accomplished by artifice in an immediate manner is more slowly brought about by natural causes. Each tributary stream which enters the main channel commonly has a greater swiftness of current than the larger stream into which it flows. It therefore bears in a mass of pebbles and builds a natural jetty or bar at its mouth, thus gradually forcing the current of the larger stream against the opposite side, creating a bar there. It is

furthermore to be noted that between the points where the river impinges against the bank there is a space of dead water or eddying currents in which the forests find it easy to make head against the river and to extend the alluvial plain.

Thus, in the process of nature, it comes about that our rivers tend to build channels in their

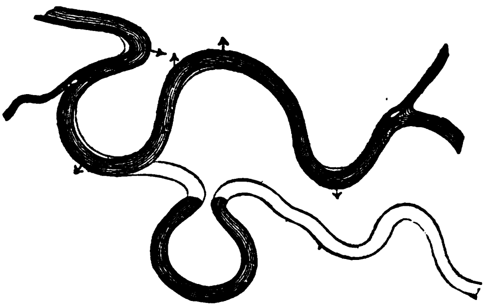

Diagram Showing the Wanderings of a Stream in an Alluvial Plain

(The arrows on the sides of the stream indicate the direction of its movement; the horseshoe-shaped pool is an "ox-bow" or "moat.")

alluvial plains which are extremely devious in their course. If the alluvial plains be wide, the river is constantly forming great ox-bow-like curves, isthmuses with narrow peninsulas such as are often seen in the lower portions of the Mississippi valley. Finally the narrow places which connected these promontories on the shore are cut through in some time of flood, the

river finding a shorter way downward to the sea, leaving its former circuit as a great pool, or moat, as it is called by the common folk along the banks of the Connecticut River. It often happens in the lower Mississippi that the course of the river around the promontory of the ox-bow is ten or more miles in length, while the space across the neck is less than a mile in distance. When the river finally breaks across the neck the whole system of rebounds of its current against the banks, from the point of change downward to the mouth, may become altered. The points which before were in process of erosion may become the seats of deposition, and those which previously were gaining may begin to wear away. In this manner a river, in time, wanders to and fro across its whole valley, taking material from one side, sorting it over, removing that part which is fine enough to be borne away by the current, and rebuilding the remainder into the alluvial plains.

We are now prepared to consider a very peculiar and most important function which these alluvial plains perform in the physical life of the earth. In such a valley as the Mississippi, we have probably not less than fifty thousand square miles of alluvial plains which have been formed of the waste removed from the rocks in the torrential portions of the streams in the mountains and hill districts of the valley. This alluvial material is, on the average, not less than fifty feet thick. It is therefore equivalent to

about five hundred cubic miles of matter. Now, this great river carries out to sea about one-twentieth of a cubic mile of sediment each year. This sediment which goes into the sea is in small part directly derived from the action of the mountain-torrents; in larger part, it is composed of waste taken from the alluvial plains by the wanderings of the various streams which constitute the Mississippi system of waters. It therefore follows that the average time required for the sediment discharged from the mouth of the Mississippi to make its way from the head-waters to the sea is not less than ten thousand years. As soon as a pebble or other bit of rock is laid away in the alluvial terrace, it begins to decay; the vegetable acids which penetrate the mass in which it finds lodgment favour its disintegration. When it is turned over by the stream at the time of encroachment on its resting-place, it probably falls to pieces, the finer bits are hurried onward by the stream, those too coarse for the current to control are again stored away in the bank to await further decay. In this manner the alluvial material lying on either side of rivers is a great storehouse, or rather we should say laboratory, in which sediments are divided and brought into a chemical condition which permits them to be taken into the control of the waters and borne away to the ocean, in order to become rebuilt into strata, which are in time, with the growth of the continents, to become dry land and be again subjected to this

erosive work. Were it not for this system of alluvial storage and decay, the seas could not be supplied with the *debris* essential for the maintenance of the life which they contain; for that life, unlike the life of the land, does not depend on the soil of the ocean floors, but upon the dissolved matter contained in the water, from which the marine animals and plants take all their store of nutrition. This nutrition comes mainly from the land-waste brought to the sea in the state of solution by the streams, and, as we have just seen, the comminution and solution of this waste depend upon the work which goes on in the laboratories of the alluvial plains.

It is true that a portion of the mineral matter contributed by the land to the sea comes from the seashore, and yet another portion from volcanic ejections which are poured out from the numerous vents of oceanic islands. The material taken from the seashore into solution by the sea-water is, however, small in quantity, and this for the reason that the ocean water has usually but a small amount of free carbonic acid to aid in its solvent work. The material contributed from volcanoes is larger in quantity than that won by the ocean waves from the coast line. A large part of this volcanic waste is, however, borne to the ocean from the land on which it falls, by the streams, which readily remove the incoherent volcanic waste by the action of their waters, and bear it to the sea.

THE SEA AND ITS WORK

PROFESSOR T. H. HUXLEY

[Part of a chapter in "Physiography: an Introduction to the Study of Nature." New York, D. Appleton & Co.

For a note on Professor Huxley see preface to his lecture in Vol. III of these Masterpieces of Science.]

AT Margate, where the estuary of the Thames ends in the North Sea, even a blind man could not stand long upon the shingly beach without knowing that the sea was busily at work. Every wave that rolls in from the open ocean hurls the pebbles up the slope of the beach; and then, as soon as the wave has broken and the water has dispersed, these pebbles come rattling down with the currents that sweep back to sea. The chatter of the beach thus tells us plainly that, as the stones are being dragged up and down, they are constantly knocked against each other; and, it is evident, that, by such rough usage, all angular fragments of rock will soon have their corners rounded off, and become rubbed into the form of pebbles. As these pebbles are rolled to and fro upon the beach they get worn smaller and smaller, until, at length, they are reduced to the state of sand. Although this sand is at first coarse, it gradually becomes finer and finer, as surely as though it was ground in a mill; and, ultimately, it is carried out to sea as fine sediment, and laid down upon the ocean floor.

On examination of the chalk cliffs, which back

the beach, it is easy to see how these suffer by the constant dash of the waves. Rain, frost, and other atmospheric agents, playing their part in the work of destruction, attack the cliff and dislodge masses of rock which come tumbling down to its base, where they accumulate as a line of rubbish. As soon as the fragments are brought within reach of the waves, they are rolled against the cliff, bruising and battering the face of the rock, while the fragments themselves are apt to get shivered in the fray.

During violent gales the breakers acquire unusual power, and are able to move rocks of enormous weight. On the western coast of Britain, where the Atlantic breakers roll in upon the shore, they have been known to exert a pressure of between three and four tons on every square foot of surface exposed to their fury. Even in summer, these waves break upon the coast with a pressure of about six hundred pounds per square foot; and, in winter, this force is often trebled. It is easy to believe that such masses of moving water can carry with them huge blocks of stone, and hurling these against the shore, can breach it just as effectually as though it were attacked by the blows of a battering-ram. In fact, whether in storm or in calm, a cannonade, more or less sharp, is constantly kept up against the coast, the ammunition being supplied by the ruins of the coast itself.

Were the waves to break upon the shore without the aid of any fragments of rock, the mere

weight of water would naturally effect some amount of destruction; but, there is reason to believe that, in most cases, this would be comparatively slight. It has been already shown that a river erodes its channel, not so much by its own friction, as by that of the sedimentary matter which it sweeps along in its course. In like manner, the wear and tear of the waves themselves is insignificant compared with that wrought by the boulders and pebbles, the gravel and sand, which they bring to bear upon the coast. Every wave carries, as it were, a number of stone hammers, with which it bruises and batters the cliffs; and, as this action is persistently repeated by wave after wave, the hardest rock is at length forced to yield.

Almost any part of our coast-line will serve to show the destructive effects of the sea. It is true, the action is much less marked in some directions than in others; while, at certain points, the sea may be engaged, not in destroying, but in actually forming land, by deposition of sedimentary matter resulting from the destruction of the shore elsewhere. As a rule, however, abundance evidence of marine waste may be seen on any visit to the seaside. Bays and coves may be hollowed out in one part of the coast, and a headland may be worn away in another: here, caves are being excavated in the base of a cliff; there, tunnels are drilled through some projecting rock; while, in many places, wall-like masses are partially detached from the cliffs so as

to stand out as buttresses, or are even completely isolated in the form of "needles," "stacks," and "skerries." A good example of marine denudation is furnished by the well-known Needles off the Isle of Wight (Fig. 43). A ridge of chalk runs across the island from east to west, and it is evident that the outstanding wedge-shaped

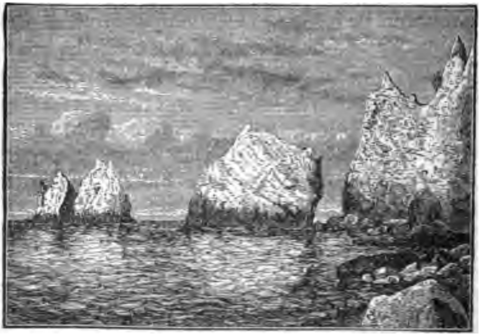

FIG. 43.—The Needles, Isle of Wight

masses were once connected with this main body, though now completely surrounded by the sea. The headlands of chalk have been beaten about by the waves until a passage has been forced at a weak point, here and there; and pillars of chalk have thus been separated from the mainland.

Where the cliffs are formed partly of hard, and partly of soft rocks, the latter will naturally be more easily attacked by the waves. The

fantastic forms which sea-cliffs assume may often be explained on this principle: the harder beds, or dykes, of rocks standing out in bold relief when the neighbouring softer rocks have been eaten away. The oldest, and, as a rule, the hardest rocks of Britain are developed in the western and northern parts of the island, and hence the sea acts with less effect upon them than upon the softer rocks in the east and south of England. Even cursory inspection of a map of England and Wales serves to show how the flowing outlines of the chalk coasts of Norfolk, Lincolnshire, and Yorkshire, contrast with the sharp outlines and bold headlands formed by the old rocks of western Cornwall, Pembrokeshire, and Carnarvonshire.

In the estuary of the Thames, the rocks are comparatively soft, consisting for the most part of sands, clays and chalk. Within the Thames Basin, then, there should be no difficulty in obtaining evidence of marine waste. Thus Sir C. Lyell has pointed out that the Isle of Sheppey has suffered considerably by the inroads of the sea, fifty acres of land having been lost within the short space of twenty years, though the cliffs there are from sixty to eighty feet in height. Herne Bay, on the Kentish coast, has lost land to such an extent that it no longer retains its shape as a bay. Going yet further out into the estuary of the Thames, we find a notable illustration of marine destruction at Reculver. This was the old Roman station of Regulbium. Not only has the sea entirely destroyed the military

wall, but the church, which in the time of Henry VIII. was nearly a mile inland, is now on the very brink of the cliff; and, indeed, it has only been saved from actual destruction by artificial means. As the two towers of the church form a well-known landmark to mariners, a causeway has been constructed on the beach to arrest the progress of the sea.

If the sea were a body of water in perfect repose, it would be utterly incapable of effecting mechanical erosion. But everyone knows that the sea in never absolutely at rest, and that, even in calmest weather, its surface is ordinarily more or less troubled with waves. It is easy to understand how these are formed. When you blow upon the surface of a basin of water, the mechanical disturbance of the air is immediately imparted to the liquid, and the surface is thrown into a succession of ripples. In like manner, every disturbance of the atmosphere finds its reflex on the surface of the natural waters. Each puff of wind catches hold of the water, and heaps it up into a little hill with the face to leeward; then the crest falls, and the water sinks down into a trough, as deep below the mean surface as the hill was high above it; but the next column of water is then forced up, only however to be pulled down again, and in this way the motion of the wave may be propagated across a broad expanse of water. Drop a stone into a pond, and the same kind of action will be seen; the water all around the spot where the stone falls is first

depressed in a little cup, and then rises again, the motion being taken up by the neighbouring water, and a succession of circles, each wider than the last, spreads over the pond, until the ripples at length die away upon the shore. If any light object, such as a cork, happens to be floating on the surface, it will serve to indicate the motion of the water below. As the waves reach it, the cork rises and falls, but it is not carried forward by the movement of the water. Exactly the same kind of action may be witnessed at sea. If a gull, for example, is seated on a wave it is simply rocked up and down, and not moved onwards.

Such simple observations are sufficient to show that the motion of the water is a movement of undulation and not of translation; it is merely the form of the wave, and not the actual water, that travels. The motion is transmitted from particle to particle, to a great distance; but the particles themselves perform very small excursions, merely vibrating up and down, or rather revolving in vertical circular paths. The general effect is similar, as has often been pointed out, to that witnessed when a gust of wind sweeps across a field of corn. Nothwithstanding the impression produced on the observer, he knows that any movement of translation is here quite out of the question; the stalks are not uprooted and carried across the field, but each stalk simply bends down before the wind and then returns to its erect position. Similarly in the open sea, the

Spain and Northern Africa. The cause of the Gulf Stream is undoubtedly to be sought in the so-called "Trade Winds," which, constantly blowing more or less from the north-eastward, give a westerly impulse to the inter-tropical surface waters of the Atlantic, and thus create the current, which sets into the gulf of Mexico. But, whether the stream, after it leaves the coasts of the United States, retains sufficient impetus to carry it to our shores; or whether, as some believe, the true Gulf Stream is lost in the middle of the Atlantic, and any warm currents felt on our own coasts are due to the predominant south-westerly winds of the temperate part of the Atlantic, is as yet uncertain.

The general course of the Gulf Stream is shown in Fig. 44. Where the water issues from the Gulf of Mexico, through the Florida Narrows, it has a temperature of upwards of 80° Fahr. and moves at the rate of between four and five miles an hour. In passing across the Atlantic the current widens and its speed is slackened, but it cools with extreme slowness, so that it carries along a considerable store of heat. The stream forms, in fact, a sharply defined river of warm water flowing over the colder water of the ocean.

When we bear in mind the effect of heat in altering the bulk of bodies, it will be understood that a body of warm water, like that of the Gulf Stream, can easily float upon water which is colder and therefore denser. When a mass of water is unequally heated, by raising its tem-

perature below, or by lowering it above, currents are at once established; and, if light matter, such as sawdust, be suspended in the liquid, the direction of these currents becomes very evident. Thus in Fig. 46, where heat is applied at the bottom of a vessel, the liquid becomes specifically lighter and therefore rises, whilst the surrounding

Fig. 46.—Currents in water by heat

Fig. 47.—Currents in water by cold

colder water being denser, runs down in streams to supply the place of that which has ascended to the surface. This is, in fact, the ordinary way in which heat is propagated through a body of liquid, and the process is called convection, to distinguish it from conduction, or the method by which heat is propagated through solid bodies. In conduction, the heat is passed on from particle to particle, and thus travels on through the mass, while in convection the heated particles themselves move. Again, if a piece of ice be dropped into a tumbler of slightly warm water, a system

of currents will also be established, as in Fig. 47. From the bottom of the piece of ice a clear stream of heavy cold liquid flows down the middle of the glass, like a stream of clear oil, while the neighbouring water, which is comparatively warm, flows upwards in currents nearer to the sides of the vessel.

Unequal cooling or heating of the great natural masses of water will be competent to produce a circulation similar to that just described. During the famous voyage of the *Challenger* the temperature of the sea at different depths was very carefully examined by means of instruments specially constructed to avoid sources of error. These observations show that, as a rule, the temperature diminishes as you descend, just as was shown to be the case in the North Atlantic Between Sandy Hook and Bermuda the bottom-water of that part of the ocean has a temperature only a little above 35° F., while, in other places, it is still lower, and may even descend below the freezing-point of fresh water. It appears that the presence of such cold water in the deeper parts of the ocean, even in tropical regions, can hardly be explained otherwise than by assuming a grand movement of water from the polar towards the equatorial regions. Dr Carpenter has brought forward much evidence to prove the existence of such a general oceanic circulation, and he refers the movement mainly to differences of density due to differences of temperature. The cold polar waters sink by their density and

form a deep layer, which creeps along the ocean-floor towards the equatorial regions; while the warmer and relatively lighter water floats on the surface in a contrary direction, or from equatorial towards polar seas. By such means, a complete circulation might be established; and it has consequently been said that every drop of water in the open ocean may, in course of time, be brought up from the greatest depths to the surface. Other meteorological conditions, however, may exert an influence of the same kind, as great as, or even greater than that produced by difference of temperature. Sir Wyville Thomson regards the influx of cold water into the Pacific and Atlantic Oceans from the south as an indraught due to "the excess of evaporation over precipitation in the northern portion of the land hemisphere, and the excess of precipitation over evaporation in the middle and southern part of the water hemisphere."

It seems probable that ocean currents are of no great importance as agents of denudation or of transport. A slow circulation of the entire mass of the ocean, brought about by such comparatively slight differences of density in the water of different parts of the ocean, as are here under consideration, might perhaps facilitate the dispersion of the finest sedimentary matter. Again, where the surface currents strike upon the shore they must do something in the work of denudation, though as a rule this will be extremely slight; the effect of currents, indeed,

is not so much to abrade the land as to carry off the results of its abrasion by other means, and to distribute the finely suspended matter, far and wide, over the floor of the ocean.

In addition to the movements of the sea which have been already noted in this chapter—the wind-waves, the surface-currents, and the general circulation—it must not be forgotten that the ocean is subject to a grand rhythmical movement. We saw, when standing on London Bridge, that the water regularly ebbed and flowed, and, what it does there, it does at every point along our coast. Twice in every twenty-four hours the margin of the sea rises, and twice it falls, so that its level is constantly shifting up and down. And yet it is a common practice to say that a given elevation is so many feet above the sea-level. Such a statement assumes that the standard taken is neither high-water mark nor low-water mark, but the mean level between the two; the water rising, at one time, as much above our standard level as it falls, at another time, below it.

As the cause of the tides is to be found outside our earth, its explanation must be deferred to a later portion of this work. It is sufficient to remark, in this place, that the great tidal wave, which travels round the earth, is an oscillatory wave, and not a wave of translation; the water simply rising and falling, but not moving onwards. While, however, this is true of the tidal wave in the ocean, it must be borne in mind that, in

narrow seas, it becomes converted into an actual wave of translation. Where the channel is contracted, as in a narrow strait, the tide may produce a rapid rush of water, or a race. If, again, the tidal wave rolls into a narrow estuary, the water becomes heaped up, and produces a sudden rush into the channel of the river: such a wave is called a bore, and is well seen in the Bristol Channel, at the mouth of the Severn, where at certain seasons the head of water attains to as great a height as forty feet.

In the estuary of a tidal river, the tide periodically agitates the water; and thus hinders deposition of sediment. The flow of the river seawards is, however, checked every time the tide comes in, and sediment is then deposited; hence, bars, or banks of sand, are common at the mouths of rivers; and, even in the estuary of the Thames, the shifting shoals indicate similar depositions. But the ebb-tide, by scouring out the estuary, prevents the formation of a true delta.

The sediment which the tidal water carries away from the mouth of a river at one part of the coast may be deposited at another point, and thus the sea may become a constructive agent charged with the formation of new land. Usually, however, the suspended matter swept away by the ebb-tide is carried out to sea, where it may be caught up by currents and thus drifted to a great distance. Hence the tides and currents assist greatly in distributing the solid matter derived from the waste of land.

Putting together what has been said in this chapter with reference to the action of the sea upon the land, it may be concluded that its work on the whole is a work of destruction, yet not exactly like that of rain and rivers. To observe this difference, it must be borne in mind that marine denudation is not equally active at all depths of the sea. The waves, as explained above, indicate only superficial agitation, and have no effect on deep water. Most of the destruction wrought by the sea is consequently confined within narrow limits, not extending deeper than a few hundred feet, and being for the most part restricted to the zone of coast below high and low water-marks. At great depths, the abrasion by slow under-currents must be extremely small, for dredgings have shown that, in deep seas, there are no large fragments of rock to assist in the work of demolition; and, even if there were, the force of the currents would probably be insufficient to move them. The great business of the sea is therefore confined to eating away the margin of the coast, and planing it down to a depth of perhaps a hundred fathoms. If this action went on for a sufficient time, the entire coast would be nibbled away, and Britain reduced to a great plain below the sea-level. The comparatively smooth surface which would be formed in this manner has been called by Prof. Ramsay a plain of marine denudation. Were such a submarine plain to be upheaved above the suface of the water, it

would immediately be attacked by rain, frost and other atmospheric agents, and would eventually be chiselled, by these means, into a variety of physical features. Denudation by the sea differs from that effected by other agents, in that it tends to produce an approximately level surface, while subaerial denudation gives rise to superficial irregularities.

EARTHQUAKES AND VOLCANOES

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[From "Physiography," New York, D. Appleton & Co.]

RAIN and river, frost and thaw, wind and wave, however much they may differ among themselves, agree in this—that they are, upon the whole, slow and certain agents of destruction. All work in the same direction, persistently attacking the solid land and sweeping away its superficial substance. Not that a particle of this substance is annihilated. Every grain stolen from the land is sooner or later carefully deposited somewhere in the sea. But, still, this gradual transference of matter, from land to water, must ultimately result in the lowering of the general level of the land to that of the sea by the action of the rain and rivers; and, in the subsequent paring down of the plain, thus formed, to the depth of which marine denudation becomes insensible. If, therefore, no hindrance were offered to the action of these agents, not only would a time come when every foot of the British Isles would be buried beneath the sea; but, inasmuch as the volume of the sea is very much greater than that of the land which rises above the sea-level, if sufficient time were granted all the dry land in the world would ultimately disappear beneath one universal sheet of water.

It is not difficult, however, to detect in the operations of nature counterbalancing forces which are capable of upheaving the deposits that have been formed on the sea-bottom, and of piling up fresh stores of solid matter upon the surface of the earth. Among these elevatory and therefore reparative agents, the most important place must be assigned to those which give rise to earthquakes and volcanoes. After the occurrence of an earthquake it is by no means uncommon to find that the level of the land has been shifted. Sometimes, it is true, the surface is depressed, but more commonly the movement is in the direction of elevation.

Perhaps the best recorded example of such upheaval is that which was observed by Admiral Fitzroy and Mr. Darwin when examining the western coast of South America. This region is peculiarly subject to subterranean disturbances, and in 1835 a violent earthquake, which destroyed several towns, was felt along the coast of Chile, extending from Copiapo to Chiloe. It was found, after the shock, that the land in the Bay of Concepcion had been elevated to the extent of four or five feet. At an island called Santa Maria, about twenty-five miles south-west of Concepcion, the upheaval was easily measured, vertically, on the steep cliffs; and the measurements showed that the south-western part of the island was raised eight feet, while the northern end was lifted more than ten feet high. Beds of dead mussels were, in fact, hoisted

ten feet above high-water mark; and an extensive rocky flat, previously covered by the sea, was exposed as dry land. In like manner, the bottom of the surrounding sea must have been elevated, for soundings all round the island became shallower by about nine feet. It is true, there was a partial subsidence shortly afterwards, but this was far from sufficient to neutralize the upheaval, and the net result showed a permanent elevation. It is considered probable, that the greater part of the South American coast has been raised several hundred feet by a succession of such small upheavals.

When an area is thus raised, the addition suddenly made to the mass of dry land may be very considerable, and will compensate for the effects of denudation continued through a long period. It was calculated, for example, by Sir C. Lyell, that, during an earthquake which occurred in Chile in 1822, a mass of rock more than equal in weight to a hundred thousand of the great pyramids of Egypt was added to the South American continent. If a single convulsion of this kind can thus raise such an amount of solid land from beneath the waters, it is obvious that these movements must be of great service in renovating the surface of the earth, and in bringing new material within reach of the ever-active agents of denudation. It is proper to remark, that an earthquake-wave is a vibration of the solid crust of the earth, which may, and constantly does, occur, without giving rise to any

permanent change in its form. Nevertheless, the wave is often accompanied by movements of elevation, or of depression, which produce permanent alterations of level of considerable magnitude.

An earthquake is just such a disturbance of the ground as would result from a sudden shock, or blow, given upward in the interior of the earth, from which, as from a centre, waves or tremors may be propagated in all directions through the solid ground. In many cases, the shock is preceded or accompanied by a rumbling noise, like that of distant thunder, or by other sounds produced by the subterranean disturbance. The earthquake-wave, as it travels along, causes the ground to rise and fall, and frequently produces irregular fissures, which may close again and thus bury whatever has been engulfed, or may remain open as yawning chasms, and thus modify the drainage of the country. The impulse may be transmitted through the earth to an enormous distance; the great earthquake which destroyed Lisbon in 1755, having made itself felt, directly or indirectly, on the waters of Loch Lomond in Scotland. If the centre of disturbance is near the sea, the water is affected even more than the land, and the water-waves may be far more destructive than the earth-waves. News has recently reached this country of the terrible devastation wrought by the great tidal wave which followed the earthquake at Lima, Arica, Iquique and other points of the coast of South America in May, 1877.

A good deal of attention has been paid by Mr. R. Mallet to the study of earthquake phenomena, or Seismology, and he is led to conclude that the origin of the disturbance is usually not deep-seated in the interior of the earth, probably never exceeding a depth of thirty miles; while in many cases, it is certainly much less. Thus he ascertained that the great Neapolitan shock of 1857 had its origin at a depth of only eight or nine miles beneath the surface. Dr. Oldham has since found that a great earthquake at Cachar, in India, in 1869, had its focus, or centre of impulse, at a depth of about thirty miles.

Although earthquake-shocks are happily of rare occurrence in this country, it must be remembered that, in many parts of the world, they are by no means rare phenomena; and, probably, it is not overstating the case to say that earthquake shocks occur, on an average, about three times a week During the year 1876, for example, no fewer than 104 earthquakes are recorded in Professor Fuchs's Annual Report; and, in the preceding year, as many as 100 days were marked by the occurrence of shocks. But, in addition to these, there are no doubt many slight disturbances in unfrequented districts, which are never recorded in such reports. The total effect produced by the causes of such disturbances must consequently be far from insignificant, even in the course of a single year.

Subterranean disturbances which commence merely with quakings of the ground often termi-

ally, each puff giving rise to clouds which shoot up to a great height, and are either dissipated or condensed in torrents of rain. Associated with the steam are various gaseous exhalations, most of which, however, are not combustible. Hence, the appearance of a column of flame, often said to be seen issuing from a volcano, must generally be an illusion, due to illumination of the vapours, partly by the sparks and red-hot stones and ashes shot out at the same time, and

FIG. 51.—Diagrammatic Section of a Cinder Cone

partly, by reflection from the glowing walls of the pipe and from the surface of the molten matter below. In the early stages of an eruption, huge fragments of rock may be ejected; for when, after a period of repose, the pent-up steam and gases at last gain vent, they violently eject the materials which have accumulated in the throat of the chimney, and choked its opening. Masses of rock, some as much as nine feet in diameter, are said to have been cast forth from the great volcano Cotopaxi, in Quito, during the eruption of 1553, and to have been hurled to a

below. It differs again from an ordinary mountain, in that it is simply a heap of loose materials and melted matter, which has been piled up layer after layer, around a hole leading down to the interior of the earth. Hence, if a volcano were cut through, it would probably present a section something like that shown in Fig. 50. Here a channel, *a*, has been opened through strata, *b*, *b*, originally horizontal, and the ejected matter has fallen all around the orifice in conical layers, each forming a mantle thrown irregularly over the preceding layer, and sloping in all directions away from the central chimney.

At the mouth of the volcanic pipe, there is usually a funnel-shaped opening known as the crater. Fragmentary materials falling back into this cup, or rolling in from the sides, form layers which slope towards the vent and therefore in the opposite direction to the dip of the volcanic beds which make up the mass of the mound. A section of a cone of loose cindery materials is given in Fig. 51, and shows the difference of dip just referred to. The molten matter which wells up the throat of a volcano, cements the loose ashes and cinders into a compact mass, where it comes in contact with them, and thus forms a hard stony tube lining the volcanic chimney.

At the beginning of an eruption, clouds of steam are copiously belched forth, showing that water has its part to play even in these fiery phenomena, The steam generally issues spasmodic-

in the volcanic pipe, and may eventually run over the lip of the crater, or force its way through cracks in the hill, forming red-hot streams which generally present a consistence something like that of treacle. These lava-torrents are often of great magnitude; thus, it was estimated that in the famous eruption of Skaptar Jokul, in Iceland, in 1783, the mass of lava brought up from subterranean regions was equal to the bulk of Mont Blanc. The lava rapidly cools on the surface, though long retaining its heat beneath the protecting crust; and, ultimately, the entire mass solidifies, forming a hard rock, more or less like a slag from an iron furnace. In different specimens, however, the lava exhibits great variations; some being dark-coloured and comparatively heavy, while others are lighter in colour and much less dense; in some cases the rock is compact, while in others it is spongy or cindery, when it is said to be scoriaceous. The little cavities, or vesicles, in this scoria or cellular lava, are formed by the disengagement of bubbles of gas or vapour, when the matter is in a pasty condition; just as the porous texture of a piece of bread is due to the presence of bubbles of gas evolved by the fermentation of the yeast. The stone largely used for scouring paints under the name of pumice is a lava of very porous texture; its name recalling its origin as the froth or scum of lava. Sometimes, the masses of lava, which are tossed into the air, are rotated during their flight, and fall as more or less rounded

bodies, known as volcanic bombs. Occasionally a very liquid lava may be caught by the wind, and drawn out into delicate fibres, like spun glass; this beautiful form is very abundant in Kilauea, a volcano in Hawaii, one of the Sandwich Islands, where it is known as Pélé's hair, its name being borrowed from that of an old goddess who was supposed to reside in the crater. Other lavas again are vitreous, and strongly resemble dark-coloured bottle-glass, when they pass under

FIG. 52.—Breached Volcanic Cones, Auvergne

the name of obsidian. This kind of lava was largely used by the ancient Mexicans for making rude knives and other cutting instruments; and a hill in northern Mexico, formerly worked for this material, is still known as the Cerro de Navajas (Spanish "Hill of Knives").

It often happens that the lava that wells up in the pipe of a volcano, breaks by its sheer weight through the rim of the crater, or even breaches one side of the conical hill. Thus Fig. 52 represents a group of small extinct volcanoes in Central France, showing cones which have been broken through in this way. In some cases the flanks of the cones are rent, and lava is then in-

jected into the cracks, forming, when cold, huge rocky ribs known as dykes. In other cases, the chimney gets choked up by a plug of hard lava, and new vents may then be opened on the side of the cone. Fig. 53 is an ideal section of a volcano, showing the dykes of lava running through the stratified deposits, and also showing two minor cones *a b*, thrown up at points where the volcanic matter has been able to force its way to the surface. Mount Etna is remarkable for having its

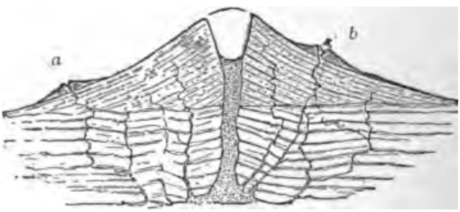

FIG. 53.—Diagrammatic Section of Volcano, with Dykes and Minor Cones

flanks studded with parasitic cones, some of which are of considerable size, one being upward of nine hundred feet in height.

After a volcano has long been silent and the large crater has been more or less filled, partly by ejected materials which had fallen back into the cavity during the last eruption, and partly by matter washed in by rain, renewal of activity through the old channel may give rise to the formation of a new cone seated within the old crateral hollow. Great changes may indeed be

effected in the character of a volcano by successive eruptions, new cones being thrown up at one time, and old ones obliterated at another. Fig 54, shows the summit of Vesuvius as it appeared in 1756, when there were no fewer than three separate cones, one within another, encircling as many craters. But about ten years afterwards the summit presented the form

FIG. 54.—Summit of Vesuvius in 1756

shown in Fig. 55, where a single cone rises from the floor of the great crater. The curious stages through which a volcano may pass are well illustrated by the story of Vesuvius.

Rather less than two thousand years ago, that mountain was as peaceful as Primrose Hill is at the present day. It seems from all accounts to have had a very regular conical shape, with a crater about a mile and a half broad. Yet its shape led hardly any one to suspect that the mountain was a slumbering volcano. Wild

vines were growing over the sides of the crater and it was in the natural fortress formed by this great amphitheatre that Spartacus the Thracian, with his little band of gladiators, took up his position at the beginning of the Servile War in the year 72 B. C. Earthquakes, as already pointed out, are often the heralds of volcanic eruptions; and the first notice which the old dwellers around Vesuvius received of its re-

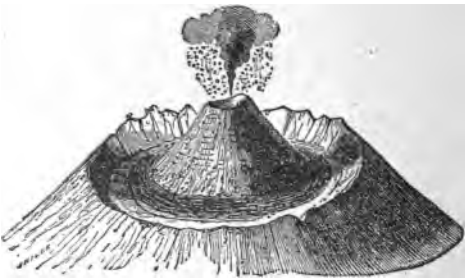

Fig 55.—Summit of Vesuvius in 1767

newed activity was from a series of earthquakes which began, as far as we know, in A. D. 63, and continued intermittently for about sixteen years. These disturbances culminated in the great eruption of A. D. 79, which has been described in two letters written by Pliny the Younger to Tacitus. The elder Pliny, the author of the famous *Historia Naturalis*, was, at that time, in command of the Roman fleet off Misenum.

On the 24th of August a cloud of unusual size and shape was seen hanging over the mountain. It is described as having had the form of a huge pine tree; and similarly shaped masses of cloud usually accompany the eruptions of Vesuvius. An enormous column of steam, mingled with ashes and stones, shoots up from the crater to a height of a thousand or twelve hundred feet, where the clouds spread out in horizontal masses, some miles in breadth, while the ashes and stones fall down in showers. Attracted by so curious a sight, the elder Pliny went to Stabiæ, about ten miles from Vesuvius, but his eagerness to witness the spectacle cost him his life. His nephew, who stayed at Misenum, describes the scene—the showers of ashes, the ejection of red-hot stones, the movement of the land, the retreat of the sea, and other phenomena characteristic of the eruption of a volcano attended by an earthquake. So vast were the quantities of ashes and other fragmentary matter ejected, either dry or mixed with water, that the unfortunate cities of Herculanæum, Pompeii, and Stabiæ were buried beneath deposits, in some places, thirty feet in thickness. It is doubtful, however, whether any true lava was erupted on this occasion. From that date to the present day, Vesuvius has been more or less active, though sometimes quiet for considerable intervals. During the great eruption just referred to, the south-western side of the original cone was destroyed, but the half which was then left has remained in existence up to the

present time, and forms the semi-circular hill known as Monte Somma. Fig. 56 is a view of Vesuvius half encircled by the cliffs of this ancient crater.

When a volcano is situated near the coast—and by far the larger number of existing volcanoes are so situated—the ashes may be showered into the sea, or be borne thither by the wind, and may, in this way, get mixed with the detrital matter which is spread over the sea-bottom. A curious series of deposits may thus be produced

Fig. 56.—Vesuvius and Monte Somma

consisting partly of materials worn away from the land by the action of the water, and partly of matter ejected from subterranean sources. In some cases, volcanic outbreaks take place actually beneath the sea, and the matter thrown up becomes mixed with the remains of shell-fish and other marine organisms. Submarine volcanoes occasionally give rise to new land, the erupted matter being piled up in sufficient quantity to form an island rising above the waters. Thus in the year 1831 an island, which Admiral Smyth named Graham Island (Fig. 57) appeared

in the Mediterranean, between Sicily and the coast of Africa, where there had previously been more than one hundred fathoms of water. The pile of volcanic matter forming this isle must have been upwards of eight hundred feet high, for the highest part of the island was two hundred feet above water; while the circumference of the mass of land was nearly three miles. After it

Fig. 57.—Graham Island, 1831

had stood above the waves for about three months, the island entirely disappeared.

It is probable that a great deal of the force by which volcanic products are brought to the surface is due to the conversion into steam of water which, in some way or other, obtains access to the deep-seated molten rocks; but, whether this is the sole source of volcanic energy or not, is uncertain. Numerous hypotheses have been advanced to explain the source and origin of the molten matter itself. Some of these attempts at explanation refer the heat to

chemical and some to mechanical causes; while others assume that it is merely the residue of the heat which the earth originally possessed, if, as seems likely, it existed at one time in a state of fusion. Dismissing, however, these vexed questions, it is sufficient to remark that some source of heat unquestionably does exist in the earth beneath our feet.

If a thermometer be buried in the ground at a depth of only a few inches below the surface, it is found to be affected by all superficial changes of temperature, and its indications show that it is cool at night and warm in the day, cold in the winter and hot in the summer. But plunged deep into the ground, or placed in a deep cellar or cavern, these variations disappear, and one uniform temperature is registered under all circumstances. What that temperature is will depend principally on the climate of the locality, the constant temperature being nearly the mean temperature of the surface.

On going still deeper, the heat is found to increase; and, at the bottom of a deep mine, it is generally so warm that the miners are glad to discard most of their clothing. At present, the deepest mine in this country is the Rosebridge Colliery, at Ince, near Wigan, which has reached a depth of 2,445 feet. Experiments on the temperature at different depths, while sinking this pit, showed that the average increase is about 1° Fahr. for every fifty-four feet. In other sinkings, somewhat different results have been

obtained, the rate of augmentation being affected by the character of the rocks bored through and by the position which the strata occupy; whether for example, they are inclined or horizontal. Thus at the Astley pit at Dunkenfield in Cheshire the rate was found to be 1° for every seventy-seven feet, but this appears to be unusually low. Perhaps it will not be far wrong to assume that the average increase is 1° for every sixty feet: such at least is the rate which was adopted a few years ago by the Royal Coal Commission in their calculations.

Even the deep sinking at the Rosebridge Colliery is but the veriest dent in the earth's surface compared with the actual radius of the globe. It gives therefore but scant information respecting the temperature of the deep-seated portions of the interior; but, assuming such a rate of increase to continue, it is evident that at the depth of only a few miles the heat would be sufficient to fuse any known rock. It is true that the melting point of a solid body may be greatly modified by pressure; and it is obvious that, at great depths, the pressure must be prodigious. Nevertheless, the eruption of lava from volcanic vents sufficiently shows that, whatever the general state of the earth's interior, there must be at least local masses of molten rock.

Additional evidence of the existence of heat at great depths is furnished by the temperature of the water yielded by certain springs. Some

of the hot springs at Bath, for example, have a temperature of 120° F. Still hotter springs occur in many countries; and, in volcanic districts, even the boiling point is occasionally reached. The most remarkable of these hot springs are those known in Iceland as geysers. Jets of boiling water with clouds of steam are intermittently thrown high into the air with great force and accompanied with loud explosions. The water generally holds silica in solution and this siliceous matter is deposited around the mouth of the hole as an incrustation called sinter. Although the Geysers of Iceland are best known, similar springs are found in New Zealand, and also in the Rocky Mountains of North America. No fewer than 10,000 hot springs, geysers, and hot lakes are said to exist within the area of the Yellowstone Park.

In some localities, hot water issuing from the ground is mixed with earthy matter; and streams of thick mud accumulate around the openings, so as to form conical hills, known as salses, or mud volcanoes. Such eruptions of mud, varying considerably in consistency and in temperature, occur, for example, in the Crimea and on the shores of the Caspian Sea. In other cases, hot vapours issue from cracks in the ground, as at the Solfatara, near Naples, where the vapours are charged with sulphur. A large industry has sprung up in the Tuscan Maremma, by utilizing the hot vapours which issue from smoking cracks, known as soffioni, and contain

particles of boracic acid which are used in the preparation of borax.

Most of the phenomena just described are probably to be regarded as representing the lingering remains of volcanic activity. When a volcano has become extinct, the effects of subterranean heat in the locality may still manifest themselves in a subdued form, in such phenomena as those of hot springs. Many volcanoes, however, which appear at the present day to be perfectly quiet, are merely dormant, and may break forth with renewed activity at any moment. The early history of Vesuvius, as already pointed out, shows that a volcano, after being silent for ages, may suddenly start forth into fresh life.

There are few better examples of an area in which volcanic action must have been rife on an enormous scale at a comparatively recent time, than that furnished by the Auvergne and the neighbouring districts in Central France. There the traveller may see hundreds of volcanic cones, known locally as "puys," still preserving their characteristic shape, in spite of long exposure; there, too, are the streams of lava just as they flowed from the craters, or burst through the sides of the cones (Fig. 52), whilst thick sheets of old lava and beds of ash are spread far and wide over the surrounding country. The district known as the Eifel, on the west bank of the Rhine, between Bonn and Andernach, offers equally striking examples of extinct volcanoes.